TREATMENT OF
OIL / WATER / MINERAL EMULSIONS
FOR BITUMEN AND HEAVY OIL

The SNC Group

OCTOBER 1984

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RE: Critical Review and Assessment of Technologies for the Separation of Stable Oil/Water/Mineral Emulsions with Emphasis on Bitumen and Heavy Oil Applications

Dear Dr. Potoczny:

We are pleased to submit the final report in six (6) copies in accordance with the contract.

We are forwarding one (1) set of the copies of the references listed in the report. The references numbering 1, 9, 49 and 52 are taken from books available from the library and are not included. Reference number 18 will be forwarded shortly.

Yours truly,

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Project Manager

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TREATMENT OF OIL/WATER/MINERAL EMULSIONS
AND EFFLUENT WATERS
FOR
BITUMEN AND HEAVY OIL

FINAL REPORT
BY
THE TECHNICAL DEVELOPMENT DEPARTMENT
SNC INC.
MONTREAL

SNC

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SUMMARY

The object of this study was to assess critically the commercial and emerging methods for separation of oil/water/minerals from an emulsion and to identify the promising methods. Literature search was carried out and contacts were made with oil producers, chemical suppliers and equipment suppliers. Response, in general, was poor because of the confidential nature of the subject.

Commercial methods, which are used for treating of the produced fluids in the oil fields, have been identified and the flow diagrams were prepared. These systems were classified in four groups, in order of difficulty occurring in the treatment of emulsions. Systems were then compared and advantages and disadvantages of these systems discussed.

Based on the analysis of the results of the survey, six systems were developed by SNC to meet the overall needs of the industry and a simplified flow sheet was prepared for each of these systems.

Capital, operating and maintenance costs of a typical commercial system were developed. Economic assessment of the commercial systems was made, using the established cost data.

Problems being encountered in the industry were analyzed and the solutions to overcome them have been incorporated in the systems developed by SNC.

Selected produced fluids were tested on pilot plant scale and the test results have been used in the technical and economic assessment.

Promising commercial methods have been identified. In-depth analysis of the emerging methods have been made. Promising emerging methods have been also identified and recommendation for future research has been made.

SECTION I

GENERAL

1.0 INTRODUCTION

The produced fluid in heavy oil and tar sands, recovered in thermal methods, contains gas and a large amount of water including soluble and insoluble solids, suspended materials and oil/water emulsions.

To produce a marketable product, oil has to be separated from the other ingredients existing in the produced fluid. For this purpose, an efficient and economical treating system has to be used. The selection of a treating system depends on a number of factors.

In thermal recovery methods, where natural water is available, or water is only needed for washing and utility purposes, effort is focused only on separation of oil, as produced water up to certain limits, may be disposed to the wells. In large oil fields, especially where steam is needed (or because of water disposal problems), the need of fresh water may become an important factor in oil recovery operations. In these cases, a water treatment system is also included in produced fluid treatment.

In the phase separation of the produced fluids, emulsions which are said to be tight emulsions, are difficult to treat in conventional treating methods. Each emulsion possesses specific characteristics, depending on the type of the oil, recovery methods and other factors. Therefore a universal method is not applicable for their treatment.

The tight emulsions contain naturally occurring emulsifying agents, solids and fines resulting in creation of a very stable emulsion. These emulsions are mostly concentrated in produced oil/water interface or tailings.

This study, includes the review of the information, the classification

1.0 INTRODUCTION (cont'd)

and comparison of the methods and assessment of the systems, to find out the most promising commercial and emerging methods of separating oil and water from emulsions. The analysis is supported by the test results for selected emulsions. Recommendations for the use of promising methods are made. These are based on the technical and economic factors involved in the operation of the systems.

2.0 LITERATURE REVIEW

An extensive effort was made to search for published and unpublished information on separation of oil and water from emulsions obtained in in-situ thermal methods. Commercial practices, current procedures and emerging methods used in breaking these emulsions were investigated.

A literature search through the SNC Library was carried out, using the computerized literature service to cover the treatment of heavy oil or tar bitumen emulsions obtained in thermal recovery methods and treatment of tailings.

The following data bases were used in our literature search:

- National Technical Information Service (NTIS)
- Canadian Institute Scientific & Technical Information (CISTI)
- Chemical Abstract (CA)
- Compendex

Contacts were made with various organizations to obtain papers, reports and other publications. These organizations and contacted persons are given in Appendix A-1.

Published reports presented at conferences and oil project reports for applications to the Energy Conservation Board of Alberta, Society of Petroleum Engineers papers, letters and documents from universities and research organizations are examples of information used in this study.

Techniques applied in this area have been known since 1941. Berkman, Egloff (1) have discussed the Demulsification extensively. This includes the heating of emulsions combined with mechanical treatment, involving pressure centrifugation and filtration.

2.0 LITERATURE REVIEW (cont'd)

Chemical and electrical dehydration and physical separation, using coarsely powdered solid or relatively small amounts of finely powdered solids, such as bentonite or zeolite, have been suggested for breaking of petroleum oil emulsions. Freezing and diluting methods and other physical dehydration techniques such as filtration and absorption have also been found to be useful in some cases. Electrical demulsification, with application of alternative and direct current have been found to be effective in desalting and dehydration of light and heavy crude oils (°API 30) and oil/water emulsions.

The conventional methods have been found effective in separation of non-stable emulsions of light oils. These methods are not efficient in separation of oil/water minerals from stable emulsions obtained in in-situ thermal methods, unless modified.

A number of techniques have been developed in recent years to overcome the problem of oil/water separation from emulsions and tailings in heavy oil and bitumen recovery, obtained in thermal methods. Some of these techniques are rarely used in oil fields as they may not be efficient to treat tight emulsions and some others are already commercialized.

An example of these systems is the high-rate, high volume oil/water separator, which is designed for specific applications, where there is a strong force for water drive. This separator can handle an input of 20,000 Bbl/day (2).

The design of this separator is based on the same principles as the API separators which can be used as a wash tank. The residence time for this separator for an input of 25,000 Bbl/day of water in the field is determined by tracing to be 19 minutes. This separator was built and installed at Big Lake Oil Field in mid 1977 and its use is limited for high water content produced fluids.

2.0 LITERATURE REVIEW (cont'd)

Another method used for oil removal from water is the parallel plate gravity type separator (3). This consists of parallel plates through which the fluid passes and oil is separated by gravity and is collected by change in level. The technique is dependent on the rising velocity of the oil drops and then the overflow rate. Removal of oil from water has been investigated theoretically and experimentally. Retention time, counter current flow and the effect of perforation of the plate, play an important role in separation. This type of separator is widely used in water treatment for fluids with traces of oil and may not be efficient in treatment of oily mineral stabilized emulsions.

A multigrade cyclindrical cartridge has also been used for separation of fine liquid-liquid dispersions. In this apparatus, the emulsion flows through the filter where separation takes place (4). In this method, a multilayer cylindrical cartridge is used. Some of these filter cartridges are applied in the oil fields for the treatment of the effluents and/or produced water, obtained from flotation of the emulsion. These filters are commercialized and are used to separate oil droplets less than 100 microns in diameter. Packed fibers are used in the cartridge and may be plugged in case of high solids content of the fluid. The layers might be chosen in such a way that they may be wetted by the dispersed or continuous phase.

Ultrafiltration is a developed method in which treatment and recovery of emulsified oil is carried out (5). A plant was designed and installed by Electrohome Limited. The city of Kitchener has operated this plant for treatment of oily water from washings. Solids and metals are removed. The oil concentration of the recovered oil phase is increased to 70 - 90%. Factors affecting the performance of the system such as flow, oil concentration, operating temperature and percent of contaminants are discussed. This type of filtration is not used in separation of oil and water, as it may not be efficient due to changes in the sizes of droplets.

This method is also described by P.R. Klinkowski (6) focussing on the separation of materials on the basis of their molecular sizes. This method is applied to pressure-driven filtration membranes used to separate multi-component solutes, according to their shapes and chemical bonding. The design of this type of equipment is explained and the suggestion made for its use in the treatment of oil emulsion and waste water effluents. This type of equipment is not used in the separation of oil and water from emulsions in oil fields, due to their inefficient performance in the case of permanent emulsions (with small molecular size) and blockage of the system with suspended solids.

This method is suitable for microfiltration due to low pressure drop in the system, and may be used in the final stage of produced water treatment in the oil field.

Electrodeposition filtration method is based on a new electrically-augmented vacuum filtration process and has been used commercially (with success for ultrafine-kaolin slurries).

Electrofiltration is particularly suited for slurries with high content of ultrafine or colloidal particles with 70% of particles less than two microns in size. This method can be used for clay dispersions as well as chemical and mineral slurries.

An electrofilter combines vacuum filtration with electrophoresis and electro-osmosis. The combination is the principal reason for the technique's high performance compared with conventional filtration. In this method, the particles migrate towards the anode, since they have a negative charge on their surface. Particles deposit on the anode membrane forming a densely packed cake.

The anode cake is dewatered by electro-osmosis, by which excess water is pumped out through the negatively charged capillaries of the cake at a high pressure. Anolytic fluid (a mixture of sodium carbonate and sodium sulfate) is fed between the anode and the membrane. The cathode is wrapped with a fabric, in this case, tightly woven polypropylene cloth for filtering out the water. This method seems to be suitable for treating of tailings and tar sand during recovery.

A new decanter centrifuge has been developed by Alfa-Laval, that increases the solid content of the sludge from 2 to 20%. It has been used in waste water treatment at clay mines. (8). This system is not used for separation of oil-water-mineral, in the oil fields, as it has not been efficient. This is due to the small difference in specific gravity of the oil and water and the low size of fine solids, which cannot be separated efficiently. Moreover, the maintenance cost of centrifuges will be high in oil/water treatment. (9).

Application of a coalescer with free water knock-out (FWKO) has been developed by NATCO in recent years. (10). The system consists of a horizontal free water knock out with a coalescing section in the front of the vessel. Gas, oil and water are separated from each other. The oil/water interface is kept in the centre line of the vessel. The coalescing section is made from various materials including polyproplene, polyvinyl chloride, stainless steel and carbon steel, depending on the design requirement.

In this process, produced fluid passes in a cross-flow pattern through the section. Oil droplets rise to the interface and solids drop to the bottom of the vessel. The coalescer covers the entire diameter of the vessel.

It is claimed that this method improves the separation by 50% or more than FWKO. It has been used widely in the U.S.A., the Middle East and also in Canada and it is still under trial.

Advantages are lower treating temperature (10 - 30°F), and production of cleaner water compared to that produced by FWKO.

A filtering technique has been used by Merland Exploration Limited, a Calgary based firm, in separation of oil and suspended solids from produced water. The system is called "filtering bag system" (11). It consists of a stainless steel vessel with a bag inside. The bag is made of polyester designed to screen particles up to 75 microns. Solids with greater particle size will remain in the bag. This system has replaced the cartridge filters. No special tools are needed to change the filter bags because the vessel is equipped with quick-release bolts.

The system faced a problem, which was overcome by an adjustment. When the oil content in the produced water was high, the filter became plugged up very quickly and the bags had to be changed every two days. To correct the problem, a new bag was designed with a liner inside. A very coarse polyester bag was added as the liner. The theory was that the inner bag would catch the oil and the outer bag would catch solids. This system has been found to be technically and economically acceptable.

Atmospheric Evaporation Dehydration is a process which has been used by Murphy (12). This emulsion breaking system has solved the problems of Lindbergh Pilot Plant treated oil, where an electrostatic system has not been effective in complete separation of water and sediment.

In this system, water is removed from crude by a water knock-out vessel, (FWKO) and the remaining emulsion is heated up to the evaporization temperature of the water. The boiling mixture is fed to the dehydrator, where it is spread in thin layers on heated, sloping trays for further evaporization. The water and lighter hydrocarbons are separated from the top and condensed and recirculated to FWKO tank as diluent to facilitate the gravity separation. The clean oil from the dehydrator is collected and pumped out. Solids are removed from the bottom.

The advantages of this system are:

- Complete evaporation of water.
- Lower fuel consumption (compared to conventional system) for FWKO because of recycling of the light material as diluent in FWKO.
- Elimination of the use of chemicals in the dehydrator, resulting in a savings of 9 cents/barrel.

An atmospheric evaporation dehydrator or an electrostatic treater are used in the final stage. Evaporation of water in the form of water/oil emulsion has been effectively carried out in a vacuum tower by Shell (13). In addition to dehydration of the oil the various petroleum products are obtained in this process. Separation of water in the emulsion has also been carried out via a flash system by Mobil Oil Canada. (14)

Application of various techniques in breaking of oil emulsions, in recent years is discussed by J. Lissant (15). This includes separation of gas, oil and water. It is suggested that the gas has to be removed from produced fluid in the first step of the treatment, to facilitate the separation of oil and water, which are in the form of an emulsion. The methods which are commonly used are said to be one or a combination of the following systems:

- Gas separators and water knockouts which are generally pressurized system to prevent any gas leakage. There are many different types of separators , which are designed on the basis of oil-water-gas ratio, viscosity of the oil and presence of solids.

- Gun Barrells. It is a vertical cylinder tank, in which the emulsion enters into the tank and extends down the center of the cylinder two feet above bottom, attached to a spreader. Gas separates from oil and is collected on the top. The emulsion travels down and is distributed between produced water and oil layer.

- Heater Treaters in which the residence time is reduced and the oil is heated and its viscosity is reduced. The emulsion is broken and dehydrated oil is separated. This system may not be efficient for tight emulsions. Therefore a further treatment is necessary.

- Centrifuge, filters, mechanical demulsification and electrostatic treaters. Some of these systems are rarely used in the oil fields today, but others such as electrostatic field are currently in use.

- The commercial methods are also described by Klaus J. Zanker (16). These include heater treaters, electric dehydrators, free water knock-out (FWKO) and chemical treater which generally use a combination of treatment methods for stable emulsions.

2.0 LITERATURE REVIEW (cont'd)

The importance of controlling the oil/water interface is pointed out and a new device of radio wave interface detecting has been introduced and results in a better treatment.

Another system which has been developed in recent years is the Disc Oil Separation Unit. The heart of the system is rotating carbon or stainless steel discs which ensure that recovered product contains a minimum of water. (17).

In this process, the floating substance is extracted from water by adhering to these rotating lateral discs and recovered material is automatically removed by scraper shoes and directed into collection vessels. The system could be supplied with a number of discs of different diameters. This system is supplied by Peter Brotherhood with the agreement of the Italian firm (OCS). This system is designed to be used in water treatment and may be an approach to new methods for emulsion treatment.

McTighe's oil-water separation is designed to reduce the oil effluent below 10 ppm, utlilizing parallel and corrigated plate theory, combined with the Petro-Pak (18).

The heart of this separation process is the Petro-Pak. It consists of a matrix of oleophilic strands, which intercept oil particles less than 20 microns in size. The system is constantly self-cleaning and requires minimum maintenance. This system is supplied by McTighe Industried Inc. and has not been used in the oil industry so far, but there might be a chance to use it effectively in effluent water treatment.

Various types of chemicals have also been used in demulsification of bitumen emulsions and their effects are evaluated (19-21).

These chemicals cover the high molecule resin compounds of ethylene oxide and proplylene oxides, used at 25 to 125°C, resulting in breaking of oil/water bitumen emulsions. Non-ionic emulsifiers have also been used with diluents. This has been carried out in conjunction with pH control media via alkaline earth metal halides. These chemicals have shown an attraction for the clays, causing their removals (22-25). Non-ionic emulsifiers have also been used with sulfonates-oxyalkylated phenol formaldehvde resins at pH 7.0 to 8.0 and is effective on stabilized clays and/or other solids (24).

The effects of chemicals on breaking of heavy oil and tar sand bitumen emulsions obtained in fire flood thermal method have also been extensively investigated. Some chemicals, even with 10% concentration, have not been effective in achieving an acceptable water content in the oil phase.

A number of chemicals are being used. However, the following have been found to be promising (26):

- Low carbon chain alkyl ketone
- Water soluble diketones
- Low carbon chain fatty acids
- Low carbon chain alcohols

A fluid-coupled electrode which is directly connected to either an AC or DC source of potential has been used to establish the electrostatic field of a coalescing system (27). The electrode fluid coupled to the driven electrode is positioned to establish two zones in the electrostatic field. The fluid is passed through the zones. The intensity of the field in the first zone decreases as the dispersed polar fluid increases, in relation to the less polar fluids of the mixture.

The intensity will be increased in the second zone. This causes the polar charged particles to be separated by passing downward and upward through two ground electrodes. This method is patented but still not used in the oil industry.

An experimental work has been carried out using high gradient magnetic separation (28). It is shown that magnetic separation may be used to separate two liquids where the continuous phase in an emulsion, is a paramagnetic liquid or a dimagnetic liquid. The liquid could be made paramagnetic by adding a paramagnetic salt to it. Reasons for difference in effect of the magnetic force are discussed in this work. Such a method,so far, has not been used in separation of oil and water from an emulsion.

To separate a heavy crude oil emulsion into gas, water and oil, an apparatus has been developed and patented using a thermo-electrostatic field (29).

In this system, emulsion passes through three zones - heating, separation and electrical;coalescence of water droplets is realized.

Oil, free of water, is obtained in the top layer and flows from the third zone over a wall into a reservoir. The wall serves the dual function of maintaining the liquid level in the third zone at an elevation where the electrodes that supply the high potential electrical fluid are at all times immersed in the oil. It also prevents brine-free oil in the reservoir from mixing with the oil that is being treated in the third zone. Gas is accumulated in the upper portion of the zone and is withdrawn.

Accumulated brine (water) is also disposed from the bottom and oil is discharged from the top. This process today, is one of the promising methods for the separation of oil from water.

The Electrostatic field (dual polarity) is also applied for dehydration and desalting of produced fluid emulsions (30). This system is a modified system of electrostatic treaters which were operated only by either AC or DC electrical sources. The advantage of this system compared to other treating methods such as settling tanks, free water knock-out and packed coalescence are: lower temperature requirement for a specified degree of oil, lower treating time and a higher degree of water separation.

Application of AC electricity with high voltage, between 12,000 and 30,000 volts, between the water interface and charged electrodes changes the polarity of the droplets 120 times per second. This has been effectively used in separation of 90% of large size water droplets (more than 100 microns). DC current, on the other hand, with positive gradient can be used for the removal of the 10% remainder of very small water droplets (1 or 2 microns in diameter).

It is suggested that the combination of these two techniques would result in complete separation of salty water emulsions from the oil.

This system is currently in use in a number of oil fields in Canada, North America and the Middle East.

Another method has been developed to break W/O and O/W emulsions with the emulsified droplets having a diameter of at least .02 micron. Emulsion is passed through a micro-pore membrane with pores having a size of at least .03 micron, and hydrophilic property and hydrophobic zones.

The system can operate at ambient temperature and under pressure. The membrane may be made of natural, synthetic or artificial fibers. Polytetrafluroethylene (PTEE), and polysulphone (pore size .003 micron) have been used experimentally. This technique is a European patent -(31).

In this method, not only the molecular size of the droplets, but also the hydrophilic and hydrophobic properties of the membranes play an important role in permitting the water droplets to pass through the hydrophilic membrane.

Separation of oil/water/minerals by filtration, using a pleated, thin channel, cross flow module has been accomplished (32). The filtering media consists of a flat sheet membrane in the form of circular array of parallel pleated thin channels -each inner wall being supported by porous packing. This method has been used for enhanced oil recovery and filtration of particulates from water flooding produced fluid.

Claims have been made that this system is more efficient for the separation of particulates than other filtering systems such as those employing cartridge filters.

Treatment of oil/water emulsions, produced from in-situ methods, have been tested by the agglomeration method using fine coal (33). As coal generally has a hydrophobic property, it has a tendancy to absorb more oil than water. This concept has been found effective in both separation of oil from tailings and cleaning of oil from minerals at the same time.

The type of coal containing more fatty acid and alcohol compounds is expected to be more effective in absorption of oil particles when it is washed by emulsions and/or tailings (33 & 37). The oil absorbed by the coal could be separated by solvent extraction and the solvent could then be regenerated. By this technique the coal can be cleaned and beneficiated to yield a higher heating value.

Flotation technique has been used for the recovery of residual bitumen from oil sand sludges. Diluent has been found to have the most significant effect on separation. It has been established that close to 100% recovery of the quality of residual bitumen could be achieved by flotation (diluting 1 volume of sludge with 2 volumes of water). (34).

This method is being used in a number of oil fields to reduce suspended mineral fines associated with organics from the produced fluids. Induced gas flotation is mostly used for efficient separation of oily minerals. The separated oily phase is sent for further treatment to other units such as filtration.

The gas flotation method has been commercialized. Sometimes these are used with nitrogen as a gas blanket. Air is also used where the oxidation of oily particles is not likely to occur.

A new clay-settling technology called electroendosmosis will be tested at Mobil Chemicals, Ft. Meade, Florida, in their planning phosphate mine. This method has been patented and developed by Monsanto Environ-Chem, using electricity to separate water from suspended solids (35). This method has not been used for oily clays and is not likely to be effective in settling of clays associated with organic compounds.

In another method, emulsion passes through the cross section of the anode made of porous ferrous ion. The passage of the current through the anode will dissolve sufficient ferrous ion in the media and break the emulsion (36).

A method in which reducing agent such as ferrous sulfate could be used to absorb the oxygen from acidic compounds in an emulsion is an area which could be considered for future investigation. This method has been patented by SNC (37), and has been found to be effective in the removal of oxygen from coal. This method needs to be experimentally investigated for oil or bitumen emulsions.

The application of coal powder technique, which has proven to be promising in the removal of oil from effluents, (33), can be combined with the addition of reducing agents in breaking of emulsions in produced waters.

3.0 CONTACTS

Contact was made with different sources which were involved in the treatment of produced oil and tailings obtained in the heavy oil and tar sands bitumen recovery, by in-situ thermal methods. This includes oil producers, equipment and chemical suppliers and research organizations. Papers, reports, and cataloques were obtained and information was also solicited by telephone.

3.1 Sources contacted were:

- Universities and Research Centres

Research Centres involved in petroleum recovery and research activities on separation of oil and water from produced fluids and tailings were contacted. The names, addresses and the contacts are given in Appendix A - Table A-1.

Some of the documents received have not been included in this report because of the confidential nature of the components. Some of the organizations have imposed restrictions on the release of the information.

- Equipment Suppliers

Contact was made with equipment suppliers to up-date information on equipment used in the oil fields for oil/water separation and produced water treatment.

The list of the names of the equipment suppliers and contacts are given in Appendix A - Table A-2.

3.0 CONTACTS (cont'd)

- Oil Companies

Oil companies which are involved in heavy oil and tar sand bitumen recovery in thermal methods were identified.

Contact with oil companies was initially made by telephone and subsequently information was solicited by letter. In general, the response was poor. Half of these companies answered positively. In spite of this, there is still a lack of data due to the confidential nature of the work. The data gaps are mostly in the areas of chemicals, operating conditions, energy consumption and the cost of the treatment of the produced fluid. The information received has been indirectly used in this study to maintain the confidentiality. The information and related sources have not been identified.

The list of the oil companies and contacts is given in Appendix A - Table A-3.

- Chemical Suppliers

Chemical suppliers were also identified.

Contact was made with chemical suppliers and positive responses were received. A number of these suppliers are active in the evaluation, testing and supplying of various chemicals for use in breaking of emulsions, solid sedimentation, water clarification and corrosion inhibitors.

The information furnished by these suppliers is of a general nature. This is because the application of chemicals could not be generalized for different types of emulsions. Furthermore, chemical suppliers who have been successful in their work are reluctant to divulge generic names of chemicals used in their Trade Name.

3.0 CONTACTS (cont'd)

- Chemical Suppliers (cont'd)

A catalogue of demulsifiers, wetting agents and water clarifiers furnished by suppliers, gives by code the indication of the chemical to be used for various applications.

The list of chemical suppliers and contacts is given in Appendix A-Table A-4.

4.0 CRITICAL ASSESSMENT OF THE EXISTING STATE OF THE ART

Commercial methods used in separation of oil and water from emulsions obtained from in-situ thermal methods are a combination of various techniques which include chemical, heating, gravity separation, electrostatic treating and evaporation methods.

Selection and use of a combination of techniques, for treatment of heavy oil and bitumen in the oil fields in Canada and the U.S.A. have been based on three main factors. These factors are, the degree API of the oil, the method of recovery, and the degree of separation of the produced fluid.

Most of the producers are interested in separating only the oil phase and are injecting the produced water to certain limits into the injection wells. A few producers are interested in treating both the oil phase as well as the produced water, with a view to re-use the water for steam generation and other purposes.

Produced fluid, in some cases, has a higher temperature than required treating temperatures and therefore has to be cooled. These fluids need less heating energy. The treatment of these produced fluids is mostly carried out by chemicals, which are injected into the well-head header for better mixing with the fluid.

The chemically treated fluid is then transferred to settling tanks, wash tanks or coalescing tanks and free water knockout is used to facilitate the separation of the gas, solid, oil and water phases.

In the case of low degree API oils (6 to 10), a diluent is added to the produced fluid before the gravity separating treatment. The dilution of the oil or bitumen causes a higher difference between the gravities of oil and water. This facilitates the separation of oil and water in gravity settling tanks.

Produced fluid with low water content is directly treated with electrostatic treaters. Sometimes this is carried out after a heater treater or heat exchanger. Other methods used in conjunction with gravity separation techniques are, the atmospheric treater for less stable emulsions and the pressurized treater for more stable emulsions. For dehydration of the oil phase from the produced fluid with low water content (0 - 5%), electrostatic treaters are generally used in the last stage after settling tanks or heater treaters. Atmospheric and pressurized treaters have been used in parallel applications where the feed stock is of variable quantity.

However, for a better separation, application of diluent, condensate and sometimes recycled oil (from produced oil or skimmed oil) have been used in a closed system. In some cases, diluent or condensate is regenerated and used again in the system. This is a modification of the technique for separation of oil and water in low API crudes. Diluent used in low API oils remain in the oil phase to dilute heavy oil or bitumen, to make it possible to pump the mixture.

Bitumen or heavy oil that are recovered in dry or wet combustion recovery methods produce more stable emulsions. This poses a more serious problem in the recovery of low degree API bitumen. In these cases, emulsions are very stable and evaporation techniques have been used for the dehydration of the oil. Vacuum units, flash traters and atmospheric evaporators are the various forms of evaporation techniques in current use.

Produced water from settling tanks, heater treaters and electrostatic treaters are generally combined in a system and treated for different degrees of separation.

In some oil fields, produced water is sent to a skim tank, (to remove skimmed oil), followed by an air flotation and filtration where most of the suspended solids are removed. These methods might be economical in the production of a clean oil phase, but they are not efficient as the gas is vented to air and could be condensed and used. If the water effluent is not treated properly and is injected into the well, this will result in the loss of the oil and may create some problems due to formation of blockages of the pores by the suspended solids present in the produced water.

Where there is a scarcity of natural water, produced water is treated to provide clean water for steam generation. The common practice is to remove oily matter by hot lime and soda treatments and solid particles by air flotation and filtration, then to polish the water by reducing the hardness of the water. The extent of these treatments depends on the chemical property of the water and the choice of the water treating method for the effluent.

These treatments will cause complete separation and will reduce losses. Cleaner produced oil and water will minimize environmental pollution. This type of treatment is generally used in large scale separation systems, where water treatment can be carried out continously.

SECTION II

COMMERCIAL OIL/WATER EMULSION TREATMENT

5.0 TECHNIQUES OF OIL/WATER EMULSION TREATMENT

A number of methods are used in the treatment of emulsions and/or tailings. The selection of treating methods depends on the type of emulsion and its characteristics including solids content, particle size distribution and its stability. A combination of the following techniques are used for the treatment of emulsions.

5.1 Gravity Separation

The main factor affecting the separation of oil and water from an emulsion is the difference between the specific gravities of water and oil. Higher differences between the gravities would lower the time of separation.

The Gravity Separation technique is effective in the separation of unstable emulsions. The gravity method has been found to be ineffective in the presence of fine minerals and emulsifiers.

In this case, heating, chemicals and diluent have been used to facilitate the separation. Description of the equipment used in gravity separation is given in the section dealing with equipment facilities.

The Gravity Separation technique is the simplest available technique and can be used where time and space are not limiting factors. In this technique, oil is separated from the top. The quality of the oil can be further improved by passing through a series of vessels in which the water and solids are removed from the bottom of the vessels.

The Gravity Separation technique is generally carried out at atmospheric pressure and at a temperature below the boiling point of water.

In exceptional cases where the gas phase is not vented and the vessel is under pressure, the process is carried out under pressure.

In gravity separation, water and oil have enough time to separate from each other in quiet residence. The vessel is designed with a residence time that is based on the settling time for water, which varies with the feed rate of emulsions.

5.2 Settling

Investigation has been carried out on gravity type separators for years. This has resulted in the development of design procedures based on basic principles.

The design of the separator depends on the type of fluid to be treated and covers the separation and retention of the solids and immiscible liquids.

Gravity type separators can neither separate nor retain soluble substances. Further, they cannot prevent the passage of emulsions and cannot break stable emulsions. Emulsions must be broken before entering into the separators.

The gravity type separators are not effective in removing oil-solid agglomerates whose densities are close to that of water. In such a case, air flotation is the process employed. This reduces the average density of the solid agglomerates and facilitates their separation.

5.0 TECHNIQUES OF OIL/WATER EMULSION TREATMENT (cont'd)

5.3 Heat Treatment

Application of heat has been used for breaking of light crude emulsions for many years. Heat increases the differences between specific gravities of oil and water. Heat also increases the vapor pressure of the water and expands its volume. This tends to rupture the film of the surfactant or oil around the water droplets in water-oil emulsions.

Heating is used in different forms in atmospheric and pressurized dehydration systems. Oils with lower degree API need a higher temperature treatment than high API oils. Heat is generally used in conjunction with other techniques. High temperature is used for the treatment of very stable emulsions where other techniques at moderate temperature fail in the breaking of the emulsion.

The temperature of emulsions at atmospheric pressure is raised to about 95°C in treaters.

Heat and pressure are used to break tighter emulsion using suitable equipment such as pressurized heater treaters ; here, water and sediment are separated at a temperature of 110°C and at a pressure below .52 MPa.

Flash distillation (160°C), evaporation dehydration, and vacuum distillation are carried out at high temperatures. In these methods, water is heated to a high temperature and evaporates and separates completely. These methods are used when other methods have been found not to be efficient.

5.3 Heat Treatment (cont'd)

Heating may also be carried out through heat exchangers and/or line heating devices or directly by a fire tube or indirectly by heated glycol.

Cooling is also used where the produced fluid is hot,in order to gain a temperature suitable for treating.

5.4 Centrifugation

A centrifuge is generally used to remove solid particles from sludges and emulsions, but it cannot be used for stable emulsions. When two immiscible liquids or suspended solids with different specific gravities are treated in a centrifuge, matter with greater specific gravity will accumulate at the greatest distance from the axis and matter with the lower gravity will be collected near the axis.

Since the centrifuges exert a force greater than the gravity of solids, its success depends on the difference in specific gravities of the substances under treatment. The centrifuge, as compared to settling tanks, reduced the settling time. However, they have limited use in oil/water emulsion separation.

This process is effective in the removal of wet oil solids and is applied where filters or coalescers are not efficient.

5.5 Dilution

Dilution is a method by which the difference between the gravities of oil and water is increased.

5.5 Dilution (cont'd)

This method is applicable for low degree API oil or bitumen where the oil is soluble in a diluent.

The water phase could also be diluted with fresh water as well as the oil phase with diluent. The water phase could be thickened by brine water to increase the specific gravity of water.

Diluents such as condensates (degree API 55 to 60) of light hydrocarbons, naphtha and recycled oil are generally used to increase the degree API of the oil phase in the system.

The combination of condensate and recycled oil (or a portion of the produced oil) or skimmed oil have been used in the oil/water separation systems.

Selection of diluent depends on the availability of the diluent and its effect on the separation of oil and water. Diluents sometimes cannot be effectively used since a portion of non-soluble organics which are present as sludge may either remain in the oil/water interface or settle down in the separators.

5.6 Flotation

Flotation is a process in which pressurized steam is saturated with a gas usually air, and when the pressure is released, the air in excess of the atmospheric saturation is released from the solution and forms bubbles approximately 30 to 120 microns in diameter. The bubbles are attracted to the surfaces of suspended particles. Thus an aggregate is formed whose average density is less than that of water and which, therefore, will rise to the surface.

5.6 Flotation (cont'd)

The Flotation technique has been used for separation of sulfides and minerals for quite some time and it has been applied for separation of coal from minerals and oil and water from waste water emulsions.

Separation of oil and water is promoted by air bubbles and is based on the difference of specific gravity of dispersed and continuous phases. This method is widely used in the treatment of oil-wet solid laden wastes. Air bubbles are attached to oil droplets, causing them to rise slowly due to a buoyancy differential. Air bubble formation is generally carried out in the two following ways:

- Saturation of the waste by air at atmospheric pressure, releasing the excess air, then forming the small bubbles by applying a vacuum of approximately 30 kPa.

- Air is dissolved into the waste under a pressure of 2 or 3 atmospheres, then the pressure is released, forming the minute bubbles.

The second method is more common in oil waste treatment and there are three variations in its application:

- Full - flow operation
  The entire waste stream is saturated under pressure followed by the subsequent release of pressure and bubble formation at the inlet of the flotation chamber.

5.6 Flotation (cont'd)

- Split - flow operation
  A part of the waste flow is pressurized and will be directed and mixed with the other part in the flotation chamber.

- Recycle operation
  A recycled stream of clarified effluent is pressurized with the air. The pressure is released and the bubble containing recycled stream is mixed with the waste water inflow.

Since the suspended particles in an emulsion are surrounded by an electrically charged double layer, chemical treatment may be needed as an aid for effective flotation. Polyvalent cations have much greater attraction for the fixed anionic inner layer. These cations, when added to the emulsion, cuase the formation of a floc which absorbs the suspended materials and is lifted by the air bubbles to the surface. Chemicals such as alum, ferrous sulfate and lime are commonly used as flocculants.

Addition of chemicals also may cause the precipitation of soluble or colloidal materials which could be separated by filtration.

5.7 Mechanical Coalescing

Observations and tests have indicated that the most effective and rapid coalescing is brought about by forcing an emulsion to pass through a comparatively fine, rigid type porous membrane possessing a fibrous structure. Coalescing is effected initially by the removal of surface film surrounding the dispersed phase droplets. Coalescing devices are based on a variety of physical and surface chemistry mechanisms which cause the small droplets of the dispersed phase to grow into larger ones.

5.7 Mechanical Coalescing (cont'd)

The selection of coalescing media is generally an important factor in this method. The media could be hydrophilic, (attracting water by wetting and allowing the oil to pass) or hydrophobic, which does the reverse action. Chemicals with surface active properties alter the surface wetting properties of the coalescing fibers and poison the media, therefore, a pre-treatment is recommended for emulsions which contain surface active agents. For a given media there is an optimum dispersion flow rate above which the efficiency of the separation decreases. This is due to local viscous shear forces within the bed being greater than the force of adhesion of droplets on the surface media.

Coalescing medias vary with the materials and the effective pore size. In some coalescing media, a fibrous material such as nylon or polyethylene is wound about a rigid spool to form a cartridge. The tightness of the wrap and the fiber diameter largely control the effective porosity of these devices. Coalescing media is sensible against the solid particles and may be plugged after a period of working time. Back flashing devices are used in the design of coalescing systems to regenerate the media by a selected fluid.

Different types of media have been found effective in the enlargement of oil droplet size including:

- Granular mixture of dissimilar metals such as aluminum and iron or carbon with a metal.

- A packed bed of mixed fibers (teflon, fiberglass dynel, polyethylene)

5.7 Mechanical Coalescing (cont'd)

- Plastic solid porous discs.
- Polyurethane foam.
- Alumina fiber, developed by ICI for separation of dispersions containing oil droplets less than 10 microns.

A coalescing system may include a coalescer to form larger droplets and a separating membrane, with hydrophilic and hydrophobic surfaces , to separate phases from each other.

5.8 Filtration

Filtration is generally used to separate suspended matter from a fluid. The fluid passes through the media and the solids are retained. Filtration could be carried out by mechanical straining or by absorption upon the media or surface and in depth.

The efficiency of separation by filters depends on the suspended solids particle size and the pore size of the filter media. If the solid particles are smaller than pore size, the particles will pass through the media and separation will not be carried out. The viscosity of the fluids play an important role in filtration as viscous fluid will plug the passage of the media.

Emulsions are sometimes destablilized by passing through a bed or a coalescing media, where the droplets are large enough to be retained. This is also true for emulsions stabilized with solid particles associated with organic compounds. Separation of solid particles by filtration resulting in destabilization of the emulsion. The latter can be done by the use of an oleophilic media to absorb organic matter on the media.

5.0 TECHNIQUES OF OIL/WATER EMULSION TREATMENT (cont'd)

5.8 Filtration (cont'd)

Filtration is carried out mainly by precoat and cartridge filters. With precoat filters, emulsion is passed through a layer of diatomaceous earth, deposited on a continuously rotating drum filter. The emulsion breaking is the result of rupturing the globules in the dispered phase when they pass through precoat material and this results in the removal of stabilized solids with oil and water separation. With the cartridge filter, polypropylene, glass fiber, woven material, cellulose fibers and stainless steel are used. Pore size of these media can be different. Generally, the minimum pore size is five microns. Plugging is a problem which is encountered in these filters. Back washing or mechanical vibration are used to remove the filtrate cake.

5.9 Chemical Methods

Chemical methods are used where an emulsion is not amenable to demulsification by physical and mechanical means, such as settling, centrifuge, filtering or coalescing, etc.

An emulsifying agent which is absorbed in the interface as a protective film on droplets, decreases the interfacial tension and improves the stability of the emulsion. The aim of the application of chemical methods in demulsification of an emulsion is to destabilize the dispersed oil droplets or to destroy the emulsifying agents by reacting with them and converting them into an ineffective form.

5.9 Chemical Methods (cont'd)

The components of an emulsion, in the system, are always in a certain equilibrium state determined by factors such as electrical charge, density, viscosity, pH and interfacial tension. Alteration of any of these factors may result in destabilizing of the emulsion. Some emulsions may be effectively broken by means of a chemical agent, which does not enter into any combination with the constituents of the emulsion, while other emulsions may require treatment with some agents which may be combined with the constituents.

The stability of an emulsion is not a function of the degree of dispersion. It is a function of stabilizing agents and properties of the interfacial film.

The stabilizing agents may be classified as ionic and nonionic materials. Some have colloidal nature or consist of solid particles which are surface active. These include hydrated gels or gums, soaps, sulphonated oils and asphaltenes.

Some of these stabilizing agents (oleophilic types) are soluble in oil. Others like water are liophilic and the rest are partly hydrophilic, partly hydrophobic and are soluble partly in both the oil and water phase creating oil/water interface. These stabilizing agents which are not ionic cannot be neutralized by ionic demulsifiers and if nonionic emulsifiers exist in the system, stabilization of emulsion remains unchanged, by the addition of ionic demulsifiers.

The selection of demulsifiers for breaking of an emulsion is dependent on characteristics of an emulsion. This includes pH, density, droplet size distribution, presence and type of emulsifying agent, suspended solid content and its distribution.

5.9 Chemical Methods (cont'd)

Although the said information might give some knowledge on which class of reagents would give the most desired result, it is preferable to carry out trial-and-error experiments; using the most suitable type of demulsifiers at different temperatures and dosages. Bottle tests are carried out for this purpose.

Improper treatment of dual emulsions (oil/water and water/oil emulsions) may invert the emulsion to the opposite type.

It has been found that the chemical recovery technique always fails if the polar phase contains a cloud of dispersed non-polar droplets. On the other hand, the technique is effective if the non-polar droplets phase contains a cloud of polar droplets. The addition of dispersed phase causes the inversion of the emulsion used in recovery techniques.

The problem of selecting an appropriate demulsifier is further complicated by the wide variation of properties of emulsifiers, crude and the connate water. At least a thousand specific formulations are currently being used around the world based on the known properties of the emulsions.

Various chemicals such as water wetting agents, water clarifiers, corrosion inhibitors, de-emulsifier and reverse de-emulsifiers are generally used in emulsion treating systems in various steps of the separation.

De-emulsifiers are used for breaking of oil-water emulsions, by neutralizing the electric forces around the dispersed droplets. There is no universal de-emulsifier even for two types of emulsion for produced fluids obtained in thermal methods, to yeild the same degree of separation.

5.9 Chemical Methods (cont'd)

Each demulsifying agent must be carefully selected by experienced workers through trial and error, on fresh samples before being applied in the oil field.

Mixing of the demulsifier with the produced fluid is also one of the important factors that must be considered. Therefore, chemicals are added to the produced fluid at the wellhead to permit a better mixing with produced fluids, before being treated in separation vessels.

Chemicals are generally diluted with an aromatic solvent and sometimes with 1 to 10% alcohol.

The dosage of the chemicals is based on the type of the emulsion to be treated and the optimum percentage varies for different chemicals but could be between 15 litre/m^3 to 1 litre/20m^3 for oil or water.

Some of the chemicals which are used by oil companies and are recommended by chemical suppliers to meet the following requirements are given in Table 5.1.

Emulsion breakers:

- Non- ionic surfactants
- Non-ionic surfactant blends

Sludge treating

- Oil soluble sulfonates

Solid precipitation

- Non-ionic, cationic surfactant blends

Reverse emulsion breakers

- Cationic polymers

TABLE 5.1

CHEMICALS FOR EMULSION TREATMENT

TYPE OF SURFACTANT AND DOSAGE

SUPPLIER	DEMULSIFIER	WETTING AGENT SOLID DROPPING	WATER CLARIFIED	REVERSE DEMULSIFIER
Tretalite	EST 109 CF-4W 200-1000 PPM	N-2613 RP-365 200-500 PPM	J-260 5-15 PPM	RP-578 -
Baker oil "treating"	28C 5-10 PPM	WT-126 10-20 PPM	169-C 3-10 PPM	MIEP805C 25-30 PPM
Alchem Inc.	1480, 1563 1565,1537	1467 -	Slugging 103,7715	8674 150R5
Champion North Western Chemicals	X-512KWS -	ZB-77 1-20 PPM	DFN-71 -	ZB-87 90 and 92
Nutro	KO and KR Series	SW Series	WC Series	-
Dichem	A-315	*	*	*

Description of some of the above surfactants are given in their information sheets.

*Available but not indicated by codes.

5.9 Chemical Methods (cont'd)

Types of chemicals which have been used in recent years, in blends of two or more of them may be composed of the following:

- Sulfonates
- Oxyalkylated phenolic resins
- Glycol oxyalkylates and polyoxylakylene glycol
- Amine oxyalkylates
- Polyglycol esters
- Oxyalkylated alcohols
- Polyglycol resins
- Propylene/ethylene oxide block polymers

5.9.1 Coagulation

Colloids are intermediate in size between suspended and dissolved solids. The most common method to remove these solids is chemical coagulation. In this process, colloids are destabilized and binded together for ease of sedimentation.

By the addition of some soluble metallic salts to a fluid,fine suspended matters are coagulated and form a precipitation or a floc.. This will occur in the presence of sufficient alkalinity.

The impurities usually bear negative charges while the metallic precipitates have positive charge and the flocs will be formed when these charges are neutralized.

The formation of a floc depends on the amount of time allowed and neutralization of electrical charges. This would occur at a definite pH of the system. When pH is adjusted, coagulates are added. Alum, ferric sulfate and ferric chloride are the common coagulants.

5.0 TECHNIQUES OF OIL/WATER EMULSION TREATMENT (cont'd)

5.9.1 Coagulation (cont'd)

Colloidal dispersion can be divided roughly into two categories: hydrophilic (clays and mineral oxides) and hydrophobic (proteins, starch and gums). One of the distinguishing characteristics is that small amounts of electrolyte added to hydrophobic systems will result in coagulation and precipitation, but will exhibit no effect on hydrophilic systems. The addition of hydrophilic colloids will stabilize a hydrophobic system and coagulation by addition of an electrolyte will not occur. Perhaps this is due to the absorption of small hydrophilic colloids on the surface of the larger hydrophobic particles, setting up a protective influence. This phenomenon can be seen in bitumen recovery tailings, in hot water extraction process.

5.10 Electrostatic Treatment

Electrostatic treatment is a technique which is mostly used for the dehydration of produced oil.

In this technique, conductive salty waters are electrically charged, coalesced and separated. This method is used for an oil with low water content (up to 5%). AC and DC electrical currents have been used in this system with voltage of 12,000 to 30,000 volts, depending on the type of emulsions.

The electrostatic field is generally applied to a fluid under a pressure of .52 MPa, and the oil temperature may be increased to 116°C, to reduce the viscosity of the oil and facilitate the removal of the water droplets and solids from the oil phase.

5.10 Electrostatic Treatment (cont'd)

Water-oil-solid separation is carried out in an equipment where clean oil is separated from the top and water and solids from the bottom.

6.0 EQUIPMENT AND FACILITIES

6.1 Gravity Separation Equipment

Settling Tank

One of the important criteria in the design of a treating system is the retention time which is generally referred to as settling time. The settling time depends on the flow and the volume.

Settling tanks are designed to meet the retention time requirement for a selected fluid, the capacity of which can be adjusted by controlling the flow, for other types of emulsions.

Settling tanks are vessels provided with baffles to force the fluid through a volume of retained water. This allows a definite time for the oil to rise above the retained water level.

The fluid is introduced into the water to increase contact between water droplets dispersed in the oil and the water media.

Skim Tanks

Skim tanks are vessels in which the oil and water are separated by the gravity separation method. In these vessels, sufficient time is allowed for free oil to rise to the surface where it can be skimmed off.

Skim tanks of various designs are constructed for specific retention times, and used primarily to separate the oil from the surface. This oil is composed of traces of the oil that has remained in the combined produced water from separators, heater treaters and/or electrostatic treaters. A simplified diagram of a constant level skim tank is given in Figure 6.1.

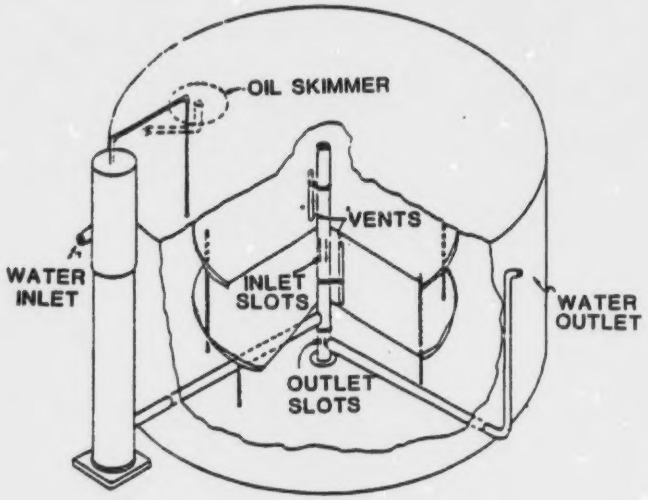


FIGURE 6.1 – TYPICAL CONSTANT-LEVEL SKIM TANK

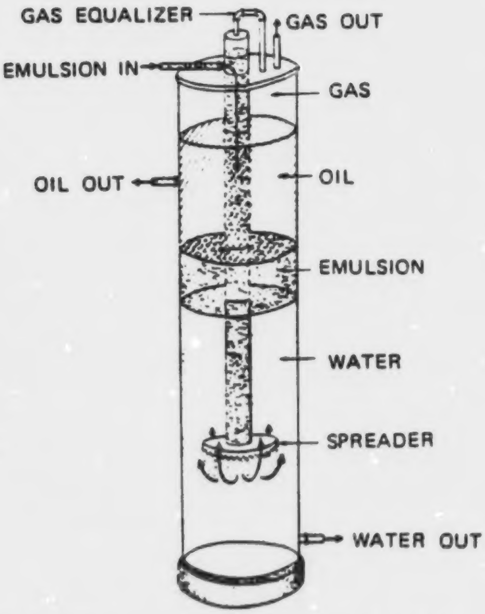


FIGURE 6.2 – TYPICAL GUN BARREL

6.1 Gravity Separation Equipment (cont'd)

Gun Barrel

Gun barrels are cylindrical vessels in which the fluid enters the tank at the top and extends down from the center of the cylinder to two feet from the bottom. The top of the line is closed and fitted with a gas draw off. There is a spreader in the bottom of the line in the tank. The fluid is distributed into the tank from the spreader; gas separates and is collected at the top. The suspended oil droplets rise through the water layer, coalesce, are separated and form the top liquid layer.

This vessel is idealy suited for treating crude oil where large volumes of fluid are handled and/or the oil and water is highly corrosive. Indirect heat is generally used to raise the temperature of the fluid, if necessary.

Gun barrel tanks may be constructed in all standard tank sizes and are normally similar to standard storage tanks. A simplified diagram of the gun barrel is given in Figure 6.2.

Corrugated Plate Separator

This separator utilizes corrugated plates and it works on the basis of the gravity difference between oil and water. Solids, oil and water are separated in order of their specific gravities. This is carried out in three zones. The fluid enters in the first packed compartment with an adjusted reduced flow, solids settle in the sand storage and large oil particles float on the surface. The fluid then enters into the corrugated plate interceptor (CIP) plate pack, where the fine droplets and sludge are separated by gravity.

6.1 Gravity Separation Equipment (cont'd)

De-oiled fluid finally enters the third compartment. Skimmers are provided to skim the oil. The height of the skimming line is adjusted so that only oil can be skimmed off. The oil level is controlled with the oil discharge in the interceptor.

This separator is more compact than other separators and is less expensive. It could only be used in retaining oil droplets of larger than fifty microns. A simplified diagram of this system is given in Figure 6.3.

Coalescing Plate Separator

This separator is a combination of gravity separation and coalescing treatment. A simplified diagram of the system is given in Figure 6.4. In this system, oil/water mixtures first enter in the inlet chamber where the bulk of the separation occurs. This is due to the effect of gravity. The remainder pass through the packs of corrugated coalescing plates for further separation.

The system does not have any moving parts and does not require filters and electricity. It operates at 100°C and within pH range of 2 to 12. But it cannot be used for fine droplets with sizes of less than five microns.

Air Flotation System

Clarification treatment consists of an initial coagulation flotation phase followed by a separation of flocs in the second phase. Satisfactory coagulation can be obtained with an appropriate use of chemical conditioner. Separation is carried out by settlement and more frequently by dissolved air flotation.

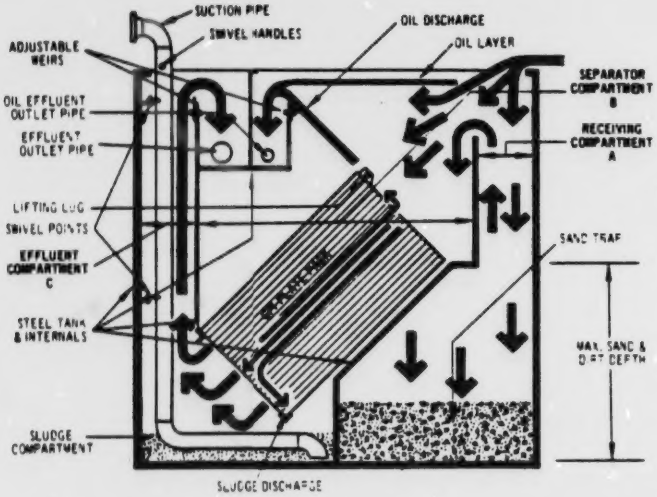


FIGURE 6.3 - CORRUGATED PLATE SEPARATOR (CPS)

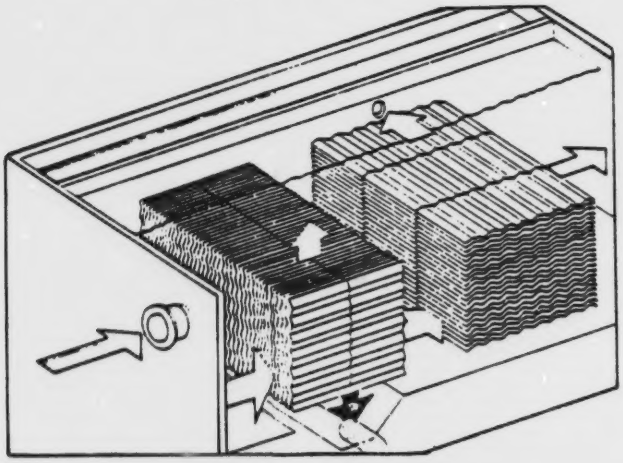


FIGURE 6.4 - TYPICAL C.P. SEPARATOR

6.0 EQUIPMENT AND FACILITIES (cont'd)

6.1 Gravity Separation Equipment (cont'd)

Settling tanks are designed to permit a large retention time and lower speed for lighter or more hydrophilic floc.

Flotation on the other hand can be used for separation of oil and fats with a specific mass of slightly less than one, from a fluid In induced air flotation systems, air is mechanically used to separate solids, oil, or organic materials from a fluid. The system consists of several flotation cells in which the air is mixed with the liquid. Air and water pass through dispersers at high velocity causing the air to form minute bubbles. Oil and suspended solids stick to the air bubbles and rise to the surface forming a froth which is skimmed and collected. Air could be also introduced to circulate and to blend with new fluid. The re-cycled liquid is pumped at high pressure, where air is injected into the fluid.

Flotation systems have been used in the oil field for treatment of the produced water which contains fine minerals associated with organic compounds.

A simplified diagram of a typical floating cell is given in Figure 6.5.

Centrifuge

There are three basic types of disc-stack centrifuges and they have different capabilities to cope with different amounts of solids in the fluid. These are: open, hermetic and paving disc designs. Disc stack centrifuge is designed for separation of two liquids and solids. The separating vessel or bowl rotates at 4500-7000 RPM. The bowl is mounted vertically and supported at the top and bottom by a vertical spindle and end bearings.

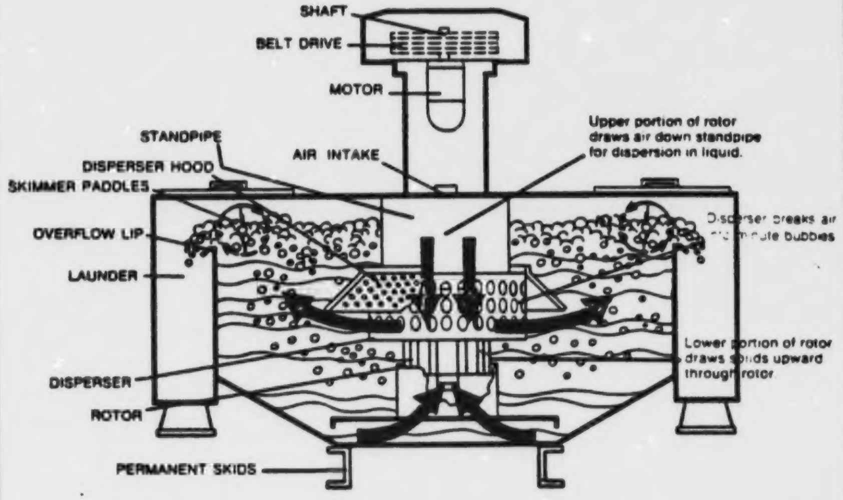

SHAFT
BELT DRIVE
MOTOR
STANDPIPE
AIR INTAKE
Upper portion of rotor draws air down standpipe for dispersion in liquid.
DISPERSER HOOD
SKIMMER PADDLES
OVERFLOW LIP
Disperser breaks air into minute bubbles
LAUNDER
Lower portion of rotor draws solids upward through rotor.
DISPERSER
ROTOR
PERMANENT SKIDS

FIGURE 6.5 - A TYPICAL FLOATING CELL

6.1 Gravity Separation Equipment (cont'd)

The fluid under treatment is fed into the distributor from the stationary inlet pipe attached to the top of the bowl casing. The feed passes round the bottom of the distributor and into the disc-stack where it is split-up between the discs resulting in a separation of components.

The denser solids are thrown rapidly outwards by centrifugal force to the underside of the discs and thrown off to a solid collector, to be discharged.

The lighter liquid phase moves inwards towards the centre between the discs and flows up to an outlet at the neck of the bowl. The heavy liquid follows the solid between separated solids and light liquid. It then flows upwards through the space between the top disc and the bowl hood to another outlet.

A simplified diagram of disc-stack centrifuge is given in Figure 6.6 and 6.7.

This type of centrifuge is efficient in separation of unstable emulsions where very fine materials are not present in the fluid.

Power consumption depends on the size and throughput of the centrifuge and increases with the increase of the throughput.

6.2 Coalescer

The Elf ANVAR Coalescer

This equipment operates on the basis of coalescing properties of the selected medias where the fluid passes through a packed bed of oleophilic ion exchange resins. The size of the oil droplet is 10 to 130 microns.

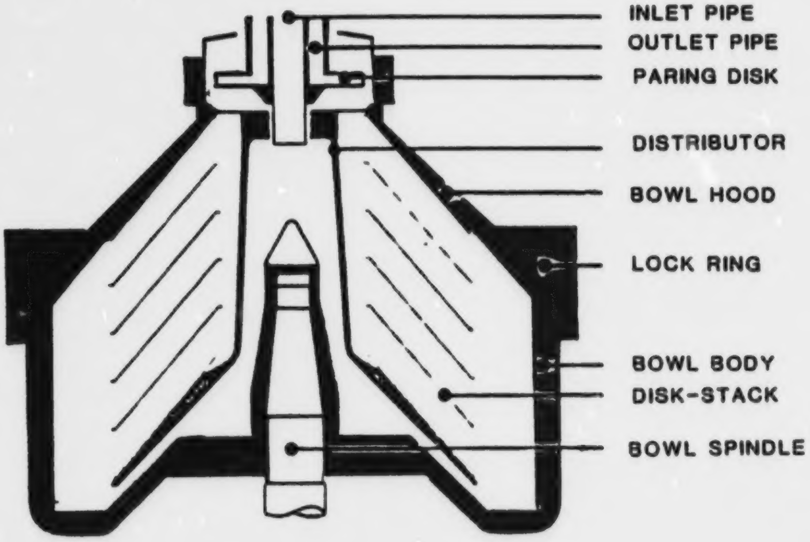


FIGURE 6.6 - CENTRIFUGE BOWL

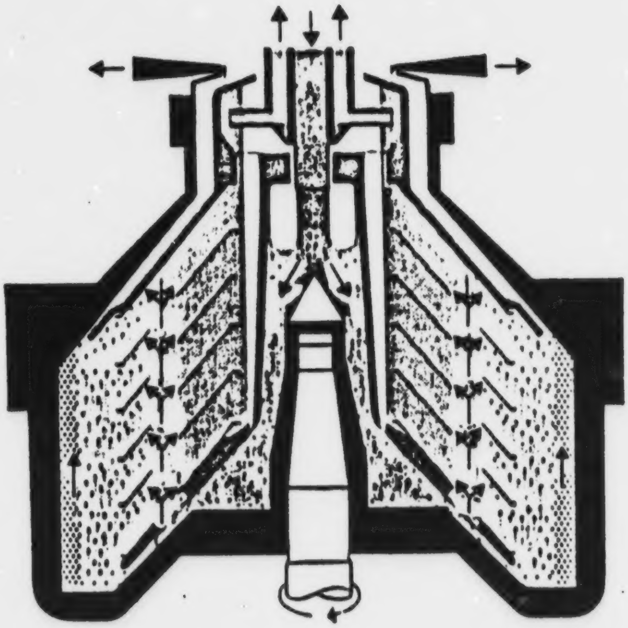


FIGURE 6.7 - CENTRIFUGE BOWL FOR SEPARATION OF TWO LIQUIDS AND SOLIDS

6.2 Coalescer (cont'd)

Oil coalesces on the resin beds which forms an oil film. When the film is thick enough, it is sheared off and carried upwards by the bulk liquid flow. The oil droplets larger than 150 microns pass through the resin bed, separate from water. This equipment is designed to produce an oil with less than 0.5 percent of water. Water free of oil and suspended solids flow out through an effluent line. This equipment cannot be used for stable emulsions.

This process is continuous and operation and maintenance costs compared to other separators are lower. A simplified diagram of this equipment is given in Figure 6.8.

Coalescing Plate Separator

This equipment is designed for pressurized oil/water separation. Separation takes place efficiently due to both gravity separation and hydrodynamic coalescence. Droplets larger than fifteen microns at oil specific gravity of 0.850 will be separated by gravity separation. Particles smaller than fifteen microns will be separated by hydrodynamic coalescence enhanced by plate configuration.

This equipment consists of a horizontal vessel with a large pre-separation chamber for solid and oil settlement. Pre-separated oil is passed directly to the oil collecting area without interference from the mainflow. In the second stage, pre-separation of oil takes place by an upward acceleration of oil and gentle deflection of water towards coalescing plates where the final separation occurs.

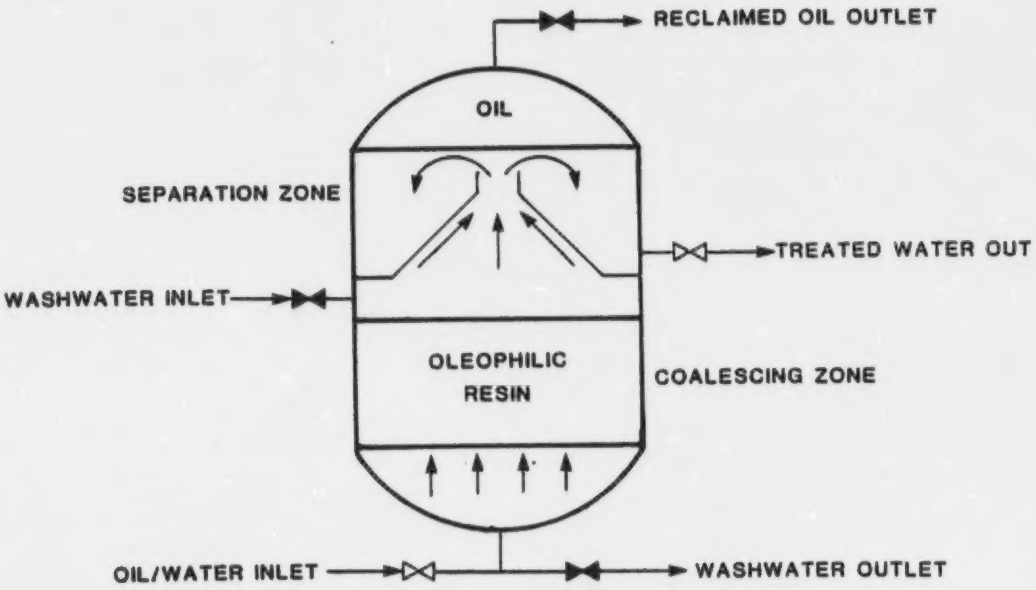


FIGURE 6.8 - GRAVER ELF / ANVAR COALESCER

6.2 Coalescer (cont'd)

This equipment is available with horizontal or vertical plates or a combination of both. A simplified sketch of this system is given in Figure 6.9.

Free-Water-Knock-Out (FWKO)

FWKO is a vessel which is used for free gravity separation of an oil and water stream. Free or demulsified water, gas and solids are typically removed from the oil phase.

The vessel is constructed in a vertical and a horizontal shape, both with a large open settling space. The water level or oil/water interface is controlled by water discharge valves. This vessel is generally under pressure to permit the fluid to be heated at a higher temperature.

The efficiency of FWKO varies and depends on temperature, percentage of free water, difference in specific gravity of oil and water and the retention time of the system.

The use of FWKO results in the reduction of the size of the treating equipment and heat input.

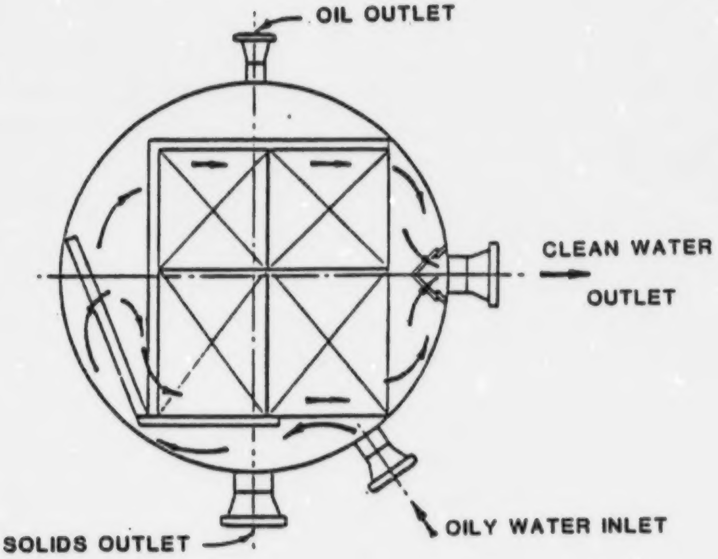


FIGURE 6.9 - COALESCING PLATE SEPARATOR

6.2 Coalescer (cont'd)

FWKO sometimes is equipped with a U-tube gas fired heater to heat the produced fluid where necessary and the fluid is directed over the fire box for more heating and a better separation of oil/water emulsion.

FWKO are designed to slow the linear flow of the oil to a point where large water drops will fall out and, to hold it there for five minutes. Separation of gas, in this vessel is similar to the cyclone separators. The fluid is fed radially so that it is thrown against the sides of the vessel and is drained to the bottom. The gas passes through the upper section and is sent to gas processing plants. Chemicals, where necessary are added to the produced fluid before free water knock out. Oil and water phases are sent separately for further treatment.

FWKO may have two or more compartments for separation of oil stream. This type of vessel is used where the volume of the oil is great and could not be handled by a single equipment. This is called an oil splitter or flow ratio control system.

FWKO is generally used in conjunction with all other methods. The oil leaving the FWKO may still contain 1.0 to 30 percent emulsified salt water. The operating temperature in atmospheric and pressurized vessels is 100°C and 120°C respectively. Simplified diagrams of a horizontal and vertical FWKO are given in Figures 6.10 and 6.11 respectively.

FWKO - Coalescer

A free water knock out developed by NATCO "Performax" includes a FWKO vessel and a coalescing section inside it. The coalescing section is made of various materials such as stainless steel, carbon steel, polyethylene and poly-vinyl chloride. Design and selection of these materials depend on the nature of the emulsion and operating conditions. The fluid is arranged to pass through the plates which cover the cross section of the horizontal vessel, in a length of 2.9 ft.

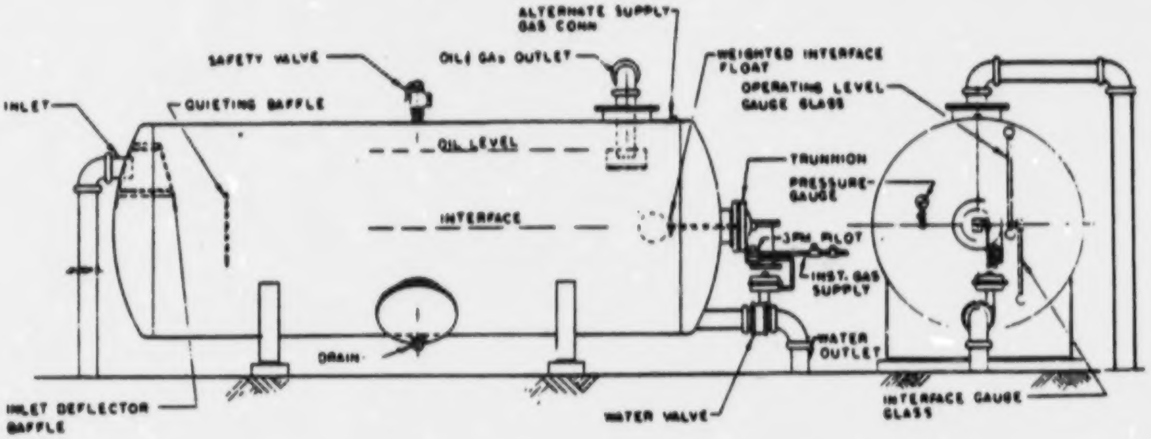


FIGURE 6.10 - TYPICAL HORIZONTAL FWKO

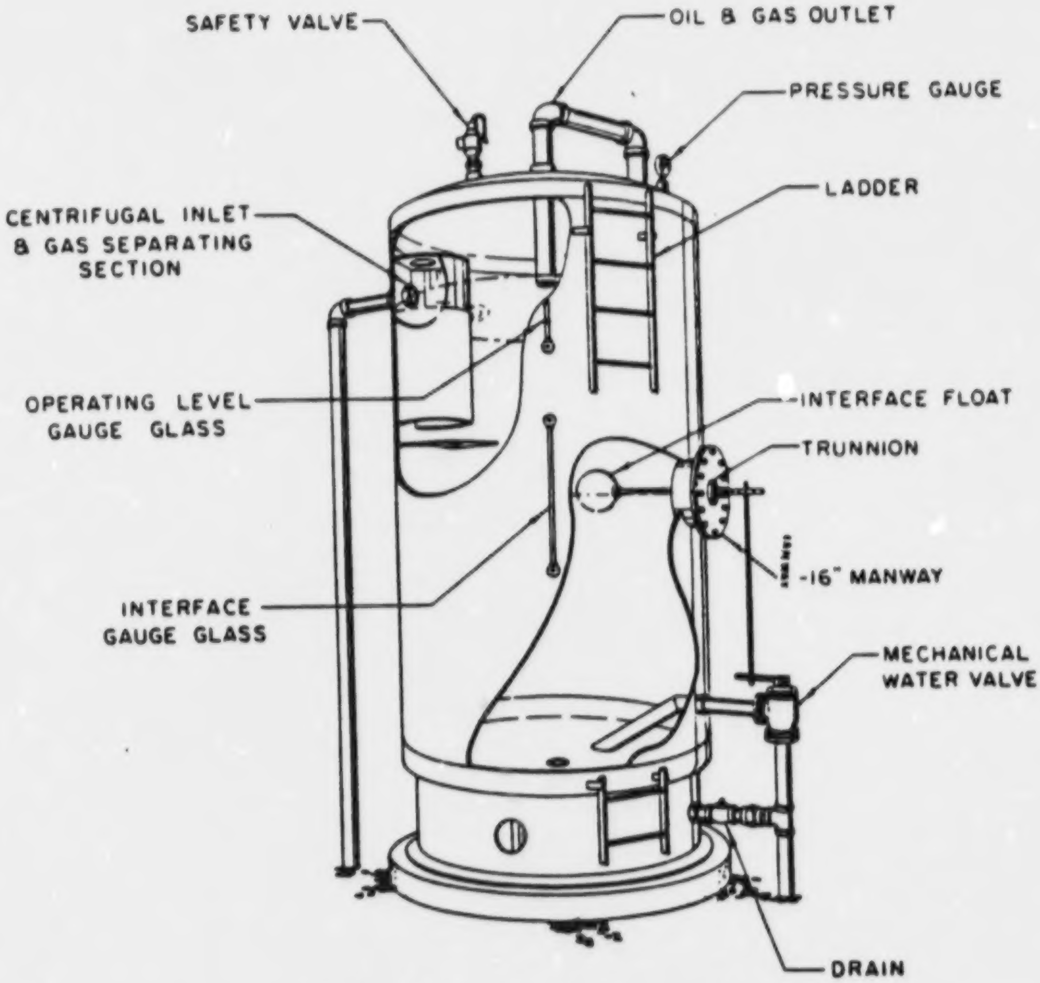


FIGURE 6.11 - TYPICAL VERTICAL FWKO

6.2 Coalescer (cont'd)

Figure 6.12 shows the outline of the NATCO Performax FWKO.

6.3 Heater Treaters

Heater treaters are used for treatment of the produced fluid in the oil. Oil can be heated directly or indirectly. In direct heating, the fluid passes over a U-shaped fire tube and then it is directed to a settling or coalescing section where it is allowed to reside until the oil emulsion is broken. Clean oil is taken out and the remainder of the emulsion is directed to other treatment facilities, such as electrostatic treaters. In indirect heating, the heat source is outside the treater to reduce the effect of corrosion of heated corrosive fluid on the heater.

Heater treaters are constructed in horizontal and vertical shapes. Both types are used in oil/water treatment in the oil field. Horizontal and vertical treaters are shown in Figures 6.13 and 6.14. Horizontal treaters have some advantages over the vertical treater as they can be constructed in large sizes and are able to handle a larger volume of oil and water emulsions. The interface is also large in the horizontal treater which may allow a more efficient separation. In vertical treaters, the fluid flows down below the fire tube. Heating and scrubbing action of the baffle trays breaks the emulsion.

Evaporators

Stripping is used to remove a small amount of light hydrocarbon materials from an effluent. Light hydrocarbons are associated with H_2S, ammonia and light oil fractions. Steam stripping can be carried out in an atmosphere or high pressure system based on the required temperature. The design of strippers is based on the vapour pressure of the materials to be treated. Steam is generally injected into the bottom of the stripper while the fluid is fed to the top of the column and flows down. Fluids with more solid materials and deposits may create plugging problems in the trays.

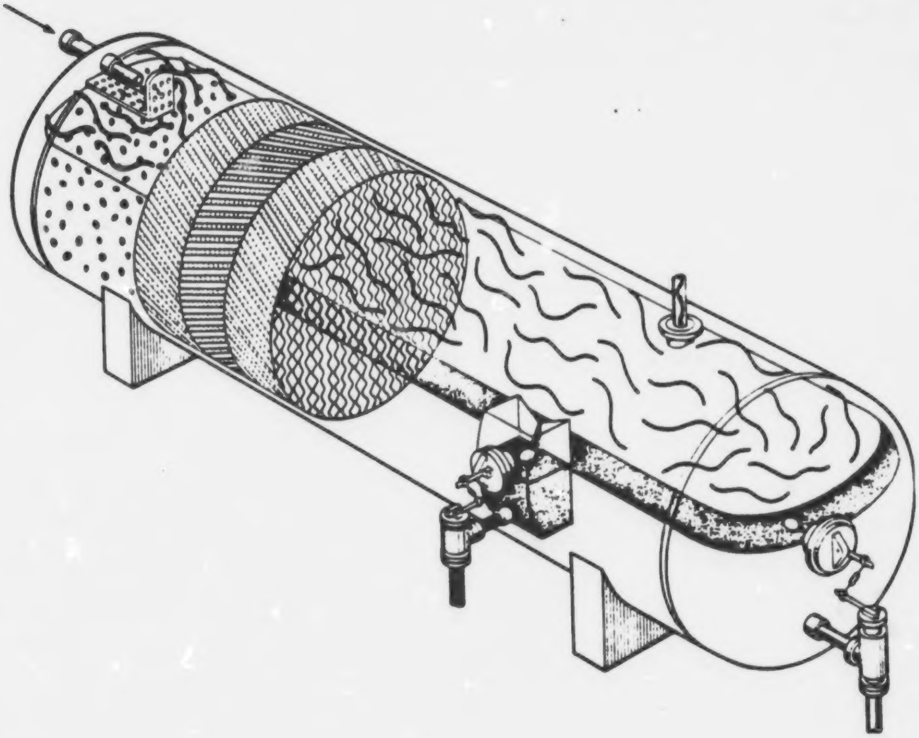


FIGURE 6.12- FWKO WITH COALESCER
(NATCO , MATRIX PLATE COALESCER)

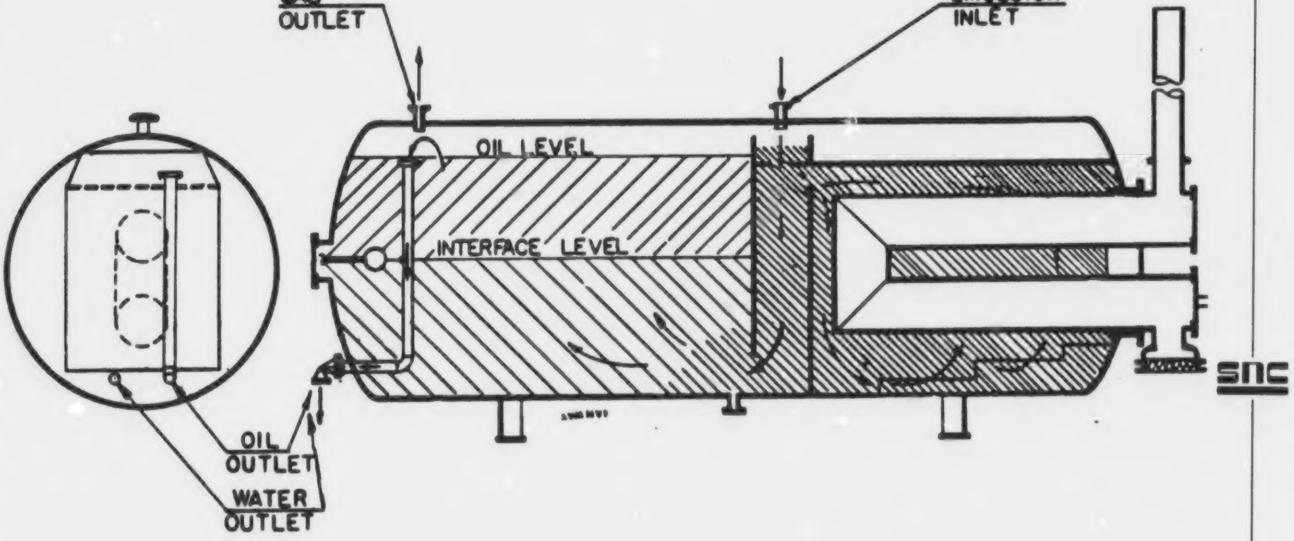


FIGURE 6.13 - TYPICAL HORIZONTAL DOWN FLOW HEATER TREATER

(SIVALLS)

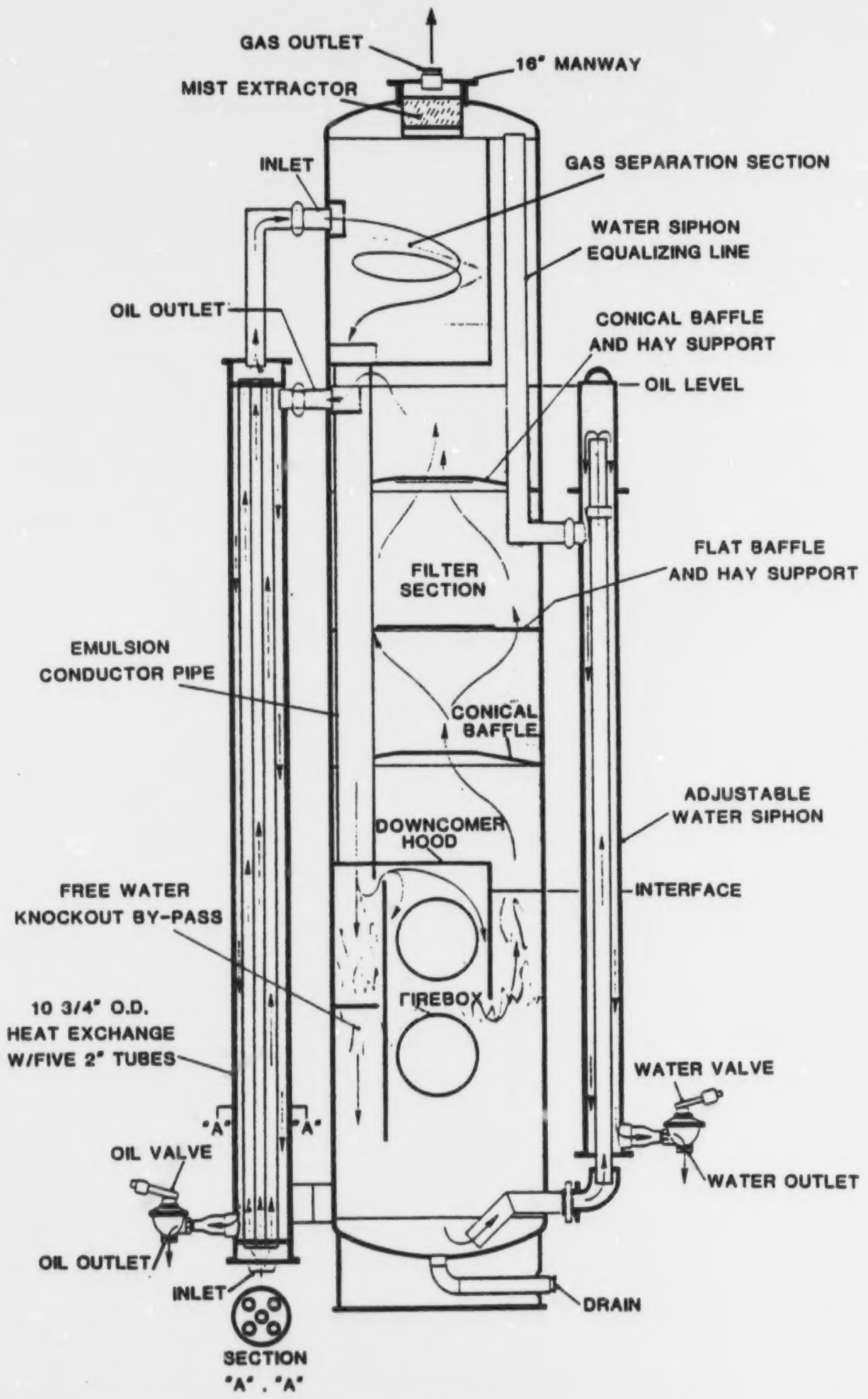


FIGURE 6.14 - A TYPICAL VERTICAL DOWNFLOW TREATER (SIVALLS)

6.3 Heater Treaters (cont'd)

Evaporator Dehydrators

This type of treatment is generally carried out in the final stage of the produced fluid treatment. Produced fluid is heated directly by gas heaters and indirectly by oil heating systems before entering the evaporator treating unit. Various types of evaporators are designed based on the type of operation for specified emulsions and the type of required products. Atmospheric flash evaporators and evaporator dehydrators are used in temperature range of 160 to 165°C, to dehydrate the produced oil. Vacuum distillation does not only dehydrate the oil but also yields valuable by-products. The advantage of this system is to recover light hydrocarbons, as condensate, and to break completely the water/oil emulsion by evaporation of water.

6.4 Electrostatic Treater

The electrical coalescence phenomenon is based on the coalescence of fine droplets of a conductive liquid, into large droplets when two immiscible liquids, one conductive and one non-conductive, pass through a high intensity electrical field. This has been used commercially for light oil dehydration and desaltation for many years.

Heavy oil with lower difference in specific gravity between oil and water and higher viscosity are more difficult to treat than light oils. Reduction of viscosity of the oil by heating, facilitates the increase in the difference between specific gravities of oil and water. Design of the electrostatic treater for heavy crudes (less than 20 °API) is improved by the addition of a heating section to the electrostatic coalescing section in a thermo-separator vessel.

6.0 EQUIPMENT AND FACILITIES (cont'd)

6.4 Electrostatic Treater (cont'd)

The electrostatic treater is effective in separation of small water droplets of less than 10 microns from stabilized water/oil emulsions.

The electrostatic treater is designed to operate with AC, DC or both electrical sources. AC voltage will alternate 120 times per second, where water droplets will be charged positively and/or negatively. Attraction will take place between the oppositely charged water droplets when they are close to each other.

In most field applications of electrostatic treaters, a single charged electrode system is used.

In an electrostatic treater, the fluid is introduced into a vessel allowing some free water to be separated. The fluid is then directed into the entire cross-section of the electrostatic field. The fluid will lose about 90% of its water in low gradient field. The remainder of the fluid passes vertically through the high gradient field, between the electrodes, where the final coalescing occurs. The larger coalesced water droplets fall by gravity to the water area. The oil with very small amounts of water is discharged through the top of the vessel.

In dual polarity electrostatic treaters, developed by NATCO, an AC field with a sinusoidal voltage is used. When one electrode is positively charged, the ground electrode is negative and suspended droplets are aligned according to these polarities. As the charges change, there is an instant where there is no electrical field at all. This change continues and the magnitude is reflected as a function of the gradient.

6.4 Electrostatic Treater (cont'd)

To remove small water droplets, a high effective unchanging electrical gradient is required to cause the coalescence of the fine water droplets. The high electrical gradient is provided by using a DC current.

Electrostatic treaters are generally operated under a pressure of .17-.28 MPa and at a temperature of about 110°C. The capacity of the treaters change and the gross throughput is up to 3500 Bbls per day, depending on the degree API of the oil.

The size of the vessel is one of the main factors of good dehydration. A suitable size of the vessel permits a smooth operation. The criteria of sizing the vessel are:

- cross sectional area at the centre line
- residence time for oil
- residence time for water

Residence time can be increased by specifying a larger diameter of the vessel for any given cross sectional area.

With two vessels with the same cross sectional area, the larger diameter vessel has a higher residence time for oil and water. With heavier oil, a larger size is required to increase the retention time.

A typical electrostatic treater and a dual polarity electrostatic treater is shown in Figures 6.15 and 6.16.

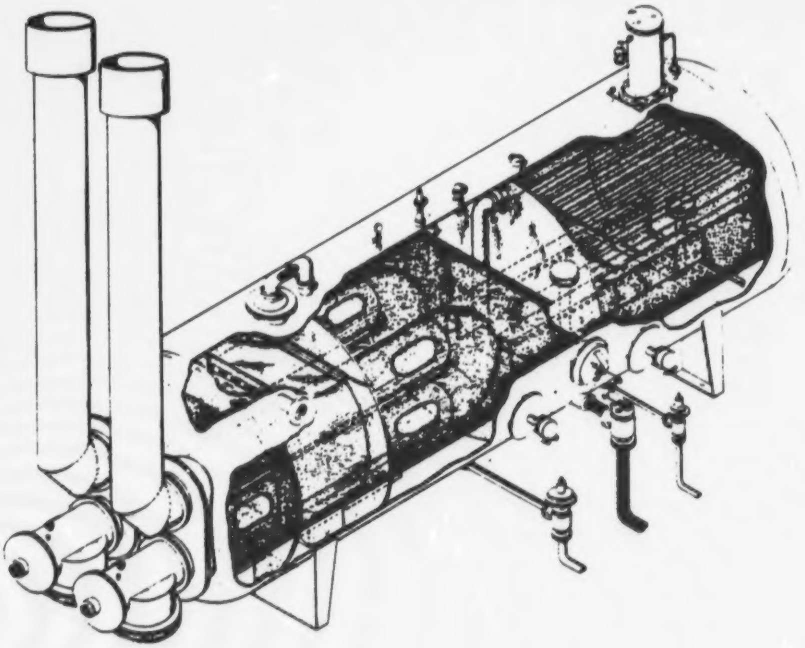


FIGURE 6.15 - TYPICAL ELECTROSTATIC TREATER

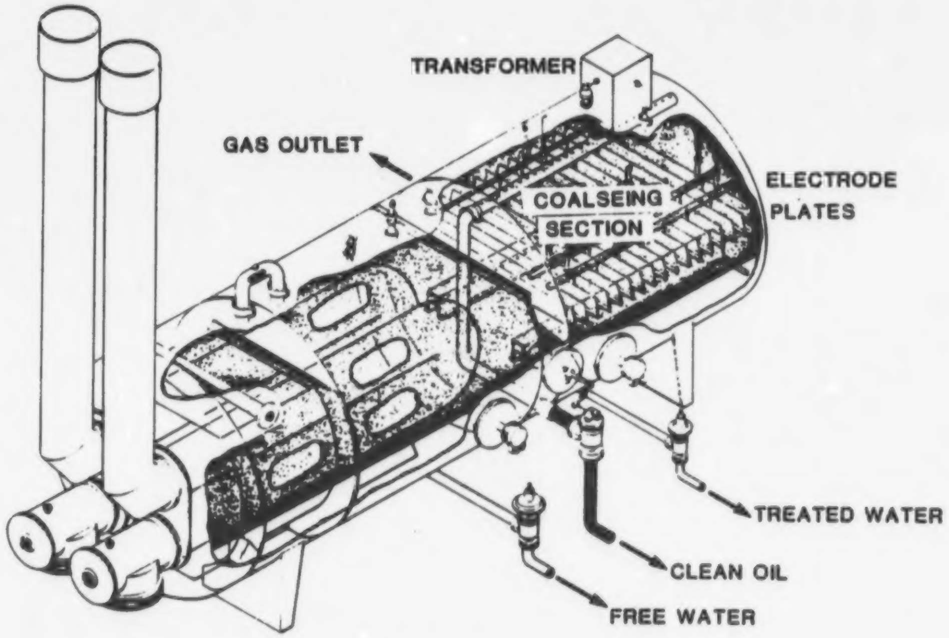


FIGURE 6.16 - DUAL POLARITY ELECTROSTATIC TREATER

7.0 CLASSIFICATION OF COMMERCIAL TREATING METHODS

Heavy oil and tar sands bitumen recovered in thermal methods contain varying amounts of free water, free oil, oil/water, water/oil emulsion, together with suspended fine materials associated with organic compounds. The presence of minerals (clay), combustion products (organic solids) and stabilizing agents increase the complexity of the phase separation.

The degree of complexity changes with the type of oil and method of recovery. A treating method which is efficient for high degree °API (34) oil may not be suitable for the treatment of low degree °API oil or bitumen (6 to 10 degrees °API). The method which is suitable for treatment of produced fluid obtained in steam thermal recovery may not be effective to the same degree for the treatment of the same oil or bitumen obtained in fire flood thermal recovery methods.

Several phase separation systems have been used commercially in oil fields, utilizing three or more techniques.

These systems are classified on the basis of the common techniques. These techniques largely depend on the characteristics of the produced fluid including temperature, water content, solid content, type of the oil, stability of the emulsions, expected product quality and finally the cost of the treatment.

Chemicals and heat are generally used in most of the treating methods, before or during the treatment, however these are not used when the produced fluids temperature is higher than required for treating. The gravity separating system is also used as the first step in the separating system where gas, oil, water and solids are separated from each other.

The above principle is used in heater treaters which are developed to reduce the time of separation. The system can be operated in atmospheric pressure or could be pressurized to heat the emulsions at a higher temperature.

Dilution, electrostatic field and high temperature evaporation techniques have been also used in the oil fields in recent years for creation of higher difference between the specific gravity of the oil and water, breaking of water in oil emulsions and evaporation of water from the oil, respectively.

Combination of some of the said systems are included in this classification. These are based on a number of factors discussed in the review of this process.

- Group I - Thermo-Physico-Chemical Systems

The selection of chemical equipment is based mainly on the properties of the produced fluid. These will differ with the produced fluid to be treated.

Systems in which the separation of oil and water is carried out only by the use of chemicals and heat are:

- A series of settling tanks
- A separating tank and a heater treater

These systems may be operated under atmospheric pressure where the emulsions could be treated at a temperature below the boiling point of water. They may also be operated under pressure .52 MPa to permit the produced fluid to be heated in the heater treater up to 116°F without boiling the water.

7.0 CLASSIFICATION OF COMMERCIAL TREATING METHODS (cont'd)

- Group I - Thermo-Physico-Chemical Systems (cont'd)

Generally a major part of the water and solids are separated in a gravity separating vessel but tight emulsions need a further treatment in heater treaters.

Produced fluids recovered in steam thermal methods, with high temperature (110-180°C) and high water content of up to 80% are treated in the system. Typical gravity separation systems used for treatment are given in Figures 7.1 to 7.5. Figure 7.1 shows a gravity separation system consisting of several settling tanks. Figure 7.2 shows the gravity settling tanks with an improvement in water separation. Figure 7.3 illustrates a gravity separation system which includes a three phase separator and a heater treater. Figure 7.4 shows a separation system with a FWKO and an atmospheric treater and Figure 7.5 shows a gravity separation system with a tank and a pressurized treater.

These systems have also been used to treat fluids with low temperature (25°C) and relatively low water content, 30 - 50%, recovered in in-situ combustion.

The typical operating conditions for treating of the produced fluids are:

	Pressure	Temperature
Settling Tank	Atmospheric	80-90°C
Coalescing Tank	.52 MPa max.	90-95°C
Heater Treater	Atmospheric	90-95°C
Pressurized Heater Treater	.52 MPa max.	93.3-121°C

The working capacity of the equipment varies depending on the properties of the produced fluids. The system could be used with a higher capacity for a higher °API oil and lower capacity for a lower °API oil.

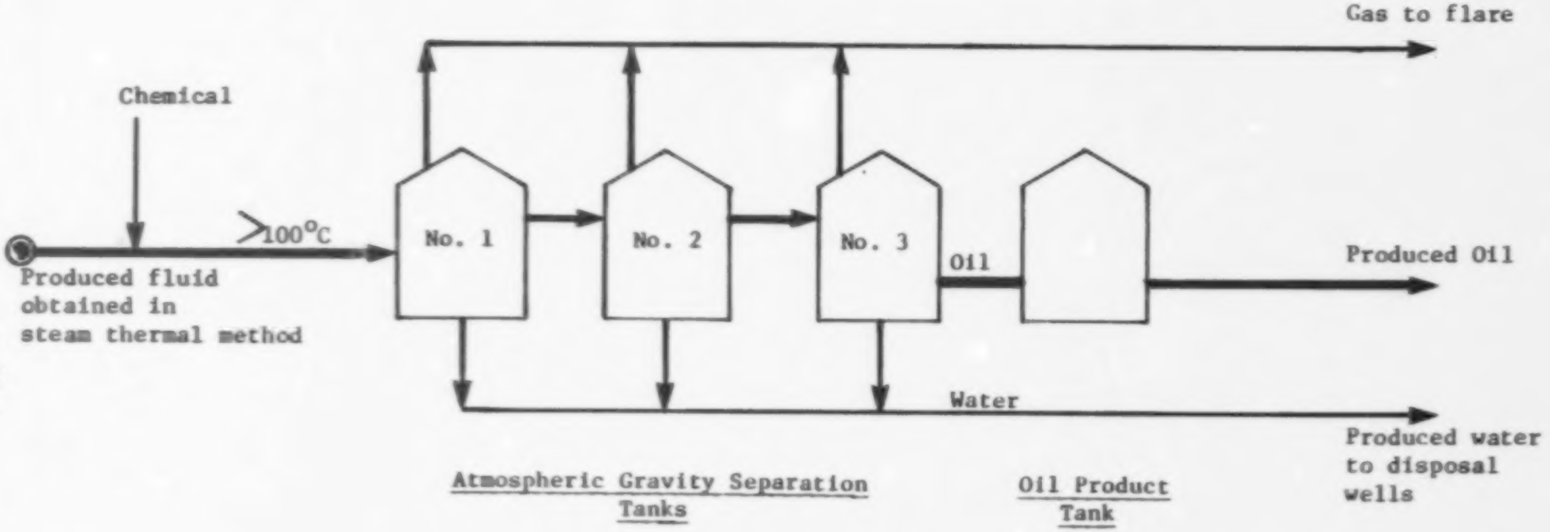

Gas to flare
Chemical
>100°C
Produced fluid obtained in steam thermal method
No. 1
No. 2
No. 3
Oil
Produced Oil
Water
Produced water to disposal wells
Atmospheric Gravity Separation Tanks
Oil Product Tank

FIGURE 7.1 - GRAVITY SEPARATION TREATMENT FOR HEAVY OIL AND BITUMEN (°API 10-15)

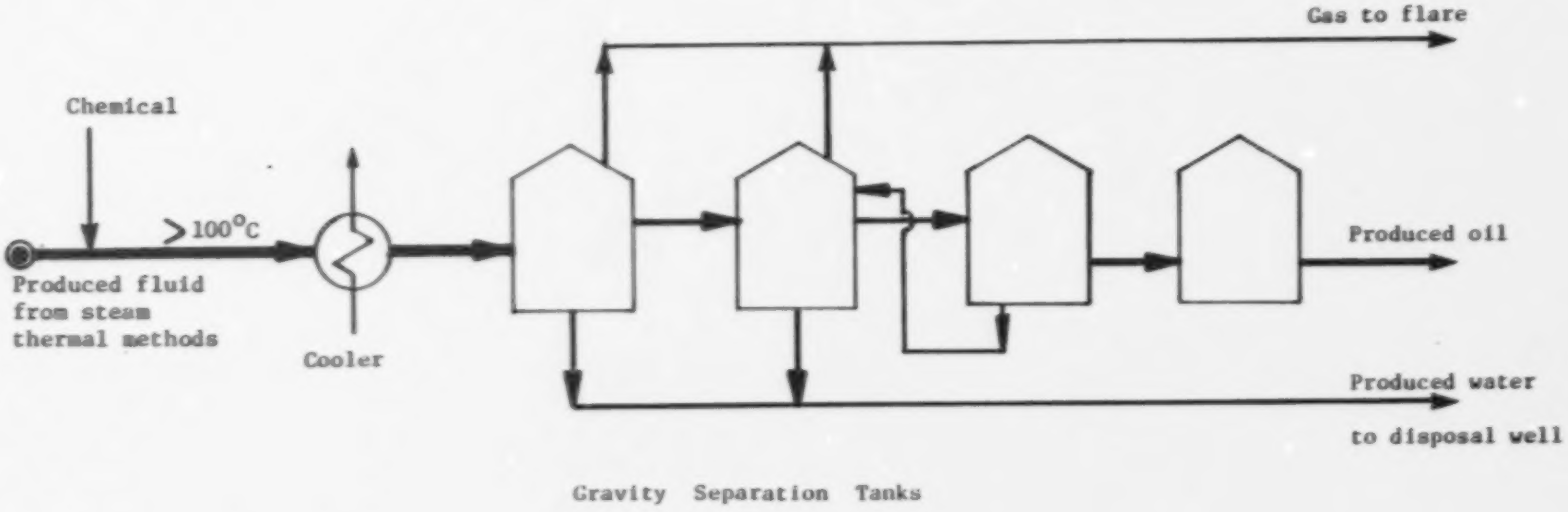


FIGURE 7.2 - GRAVITY SEPARATION TREATMENT FOR HEAVY OIL (°API 10-12)
WITH IMPROVED WATER SEPARATION

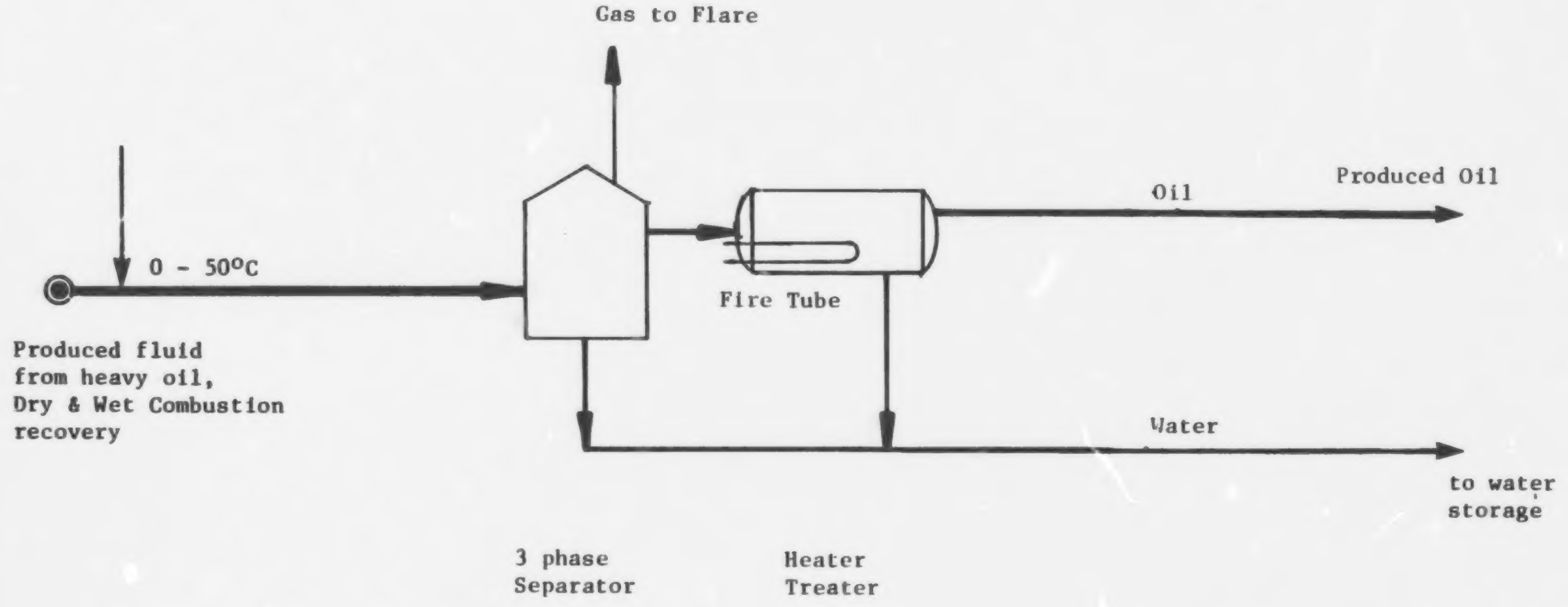


FIGURE 7.3 - GRAVITY SEPARATION TREATMENT FOR HEAVY OIL (°API 10-15) USING 3 PHASE PRESSURIZED SEPARATOR AND HEATER TREATER

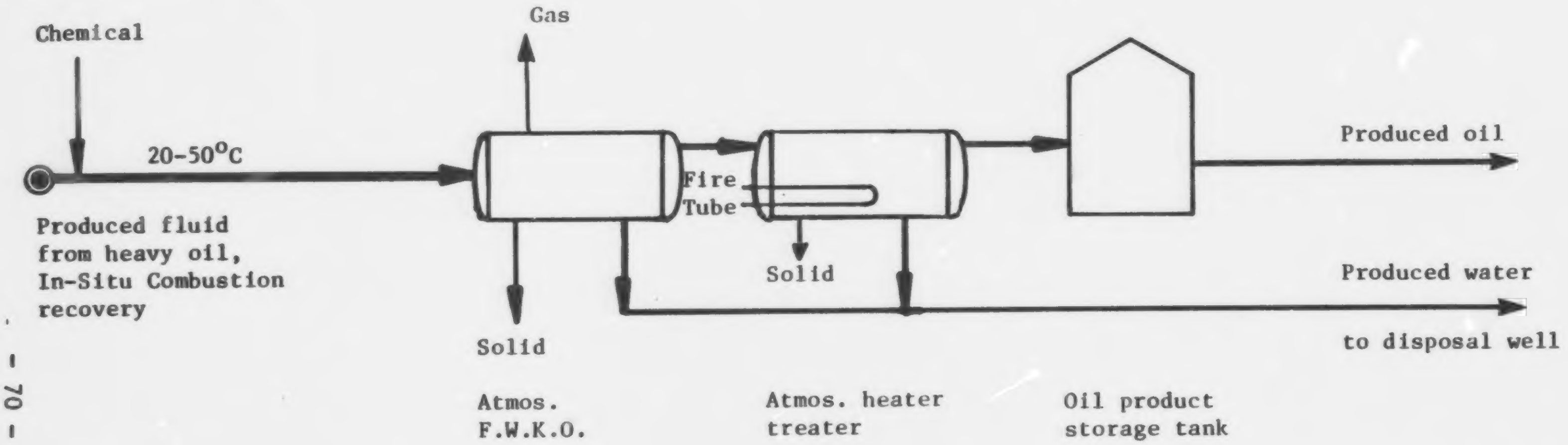


FIGURE 7.4 - GRAVITY SEPARATION TREATMENT FOR HEAVY OIL(°API 10-15)
WITH F.W.K.O. AND HEATER TREATER

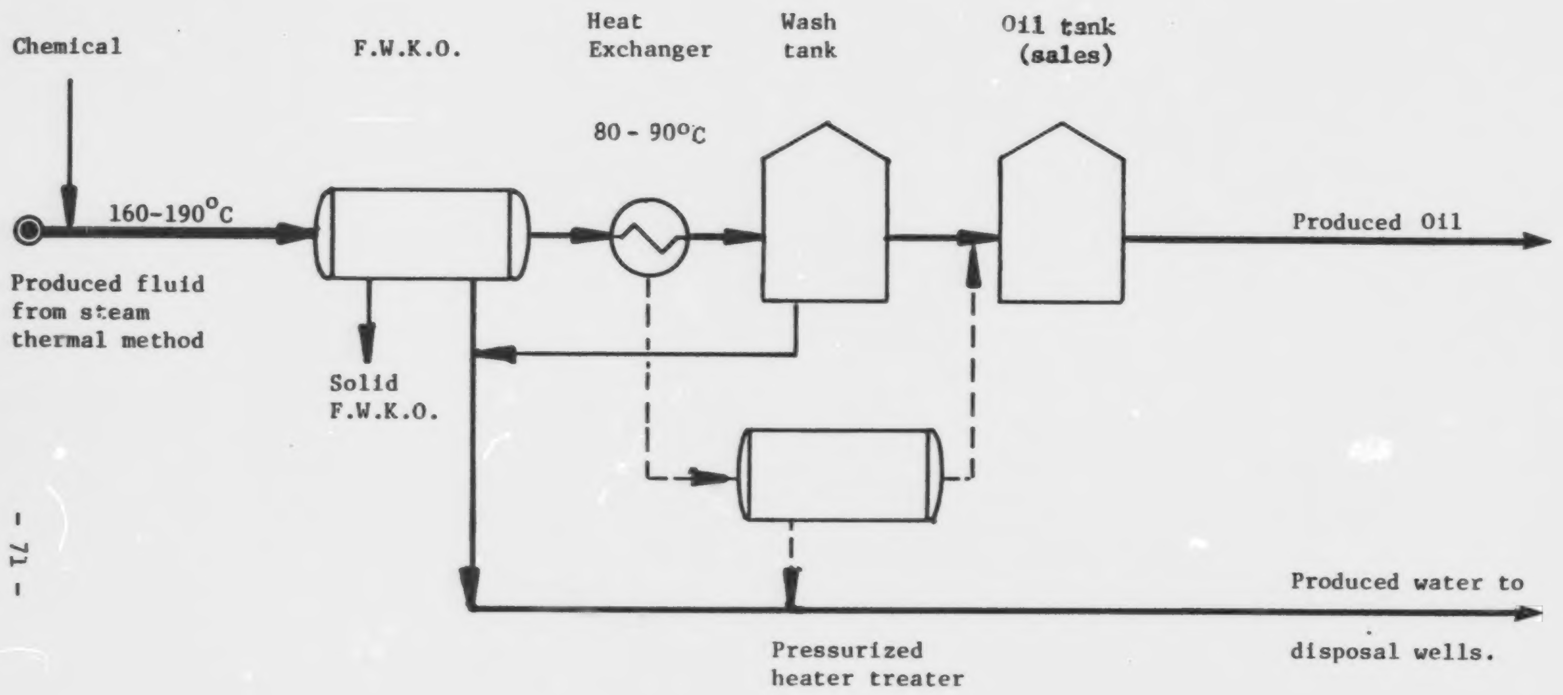


FIGURE 7.5 - GRAVITY SEPARATION TREATMENT FOR HEAVY OIL (°API 10-15) WITH WASH TANK AND PRESSURIZED HEATER TREATER

7.0 CLASSIFICATION OF COMMERCIAL TREATING METHODS (cont'd)

- Group I - Thermo-Physico-Chemical Systems (cont'd)

The time of separation for settling and separating vessels is high, 24-96 hours . It is lowered to 1 - 5 hours by using heater treaters.

Disposal of produced water in these systems is generally injected into disposal wells. The oil product, BS & W is kept below 0.5%.

Separating tanks in this class are mostly used to separate gas solid, free water and oil from the produced fluid. Skim tanks are used in gravity separation of oil from produced water (effluent).

Coalescers and coalescing plate separators are rarely used in oil fields because they are not efficient in separating fine oil or solid particles (lower than fifteen microns) from water.

A combination of free-water-knock-out and special types of coalescers have been used in the first stage of produced oil separation.

- Group II - Thermo-Electrostatic Treater

The electrostatic treater can be used where water in oil emulsion cannot be broken by the application of both gravity separating tanks and heater treaters. Electrostatic treaters are generally used alone where there is low water content in the produced fluid. They are also used at the final stages of treating systems for the final dehydration of the oil phase.

- Group II - Thermo-Electrostatic Treater (cont'd)

In the electrostatic treater, heat reduces the viscosity and electrical coalescence causes an increase in water droplet size, resulting in a better settlement of the water droplets. High voltage, causes a higher degree of water separation but this will be effective where conductive and non-conductive phases are under treatment.

The electrostatic treater is generally equipped with a fire tube heater. Gas, oil, water and solids are separated and clean oil is removed from the top.

The range of operating conditions are:

- Temperature: 95 - 125°C
- Pressure: .24 - .52 MPa

The retention time is higher for oil than water. High level of oil/water interface, containing solid particles may cause a short circuit.

Treatment of the produced fluid in the electrostatic treater is the same as the pressurized heater treater, in which chemically pre-treated produced fluid is heated under pressure, and in addition the oil phase is exposed to an electrostatic field, (Figures 7.6 to 7.10). Figure 7.6 illustrates a separating system with an electrostatic treater for low water content fluid. Figure 7.7 illustrates a separating system with a FWKO and an electrostatic treater for higher water content. Figure 7.8 shows a separation system with a FWKO and an electrostatic treater and produced water treatment facilities. Fig. 7.9 illustrates a separation system using FWKO as the electrostatic treater and a skim tank.Figure 7.10 shows a separating system with fresh water injection in an electrostatic treater and Figure 7.11 shows separation of a fluid by the use of a diluent and an electrostatic treater.

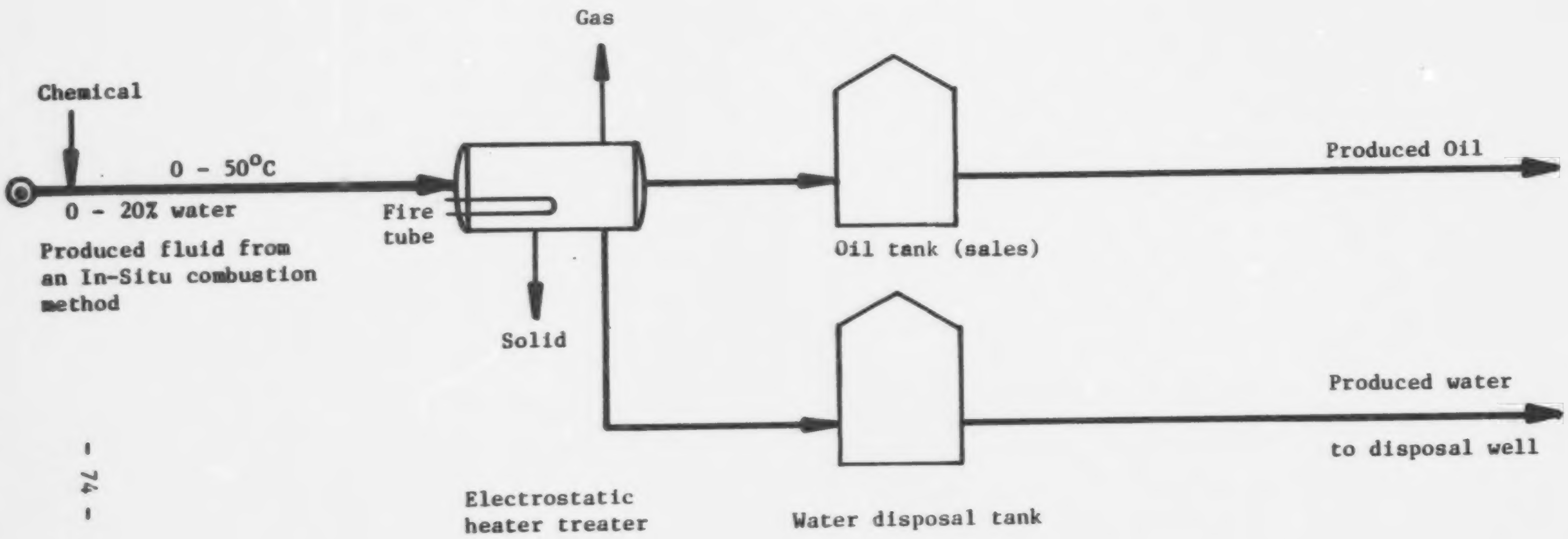

Gas
Chemical
0 - 50°C
0 - 20% water
Produced fluid from an In-Situ combustion method
Fire tube
Solid
Electrostatic heater treater
Oil tank (sales)
Water disposal tank
Produced Oil
Produced water to disposal well

FIGURE 7.6 - TREATMENT FOR BITUMEN EMULSION WITH LOW WATER CONTENT USING ELECTROSTATIC HEATER TREATER

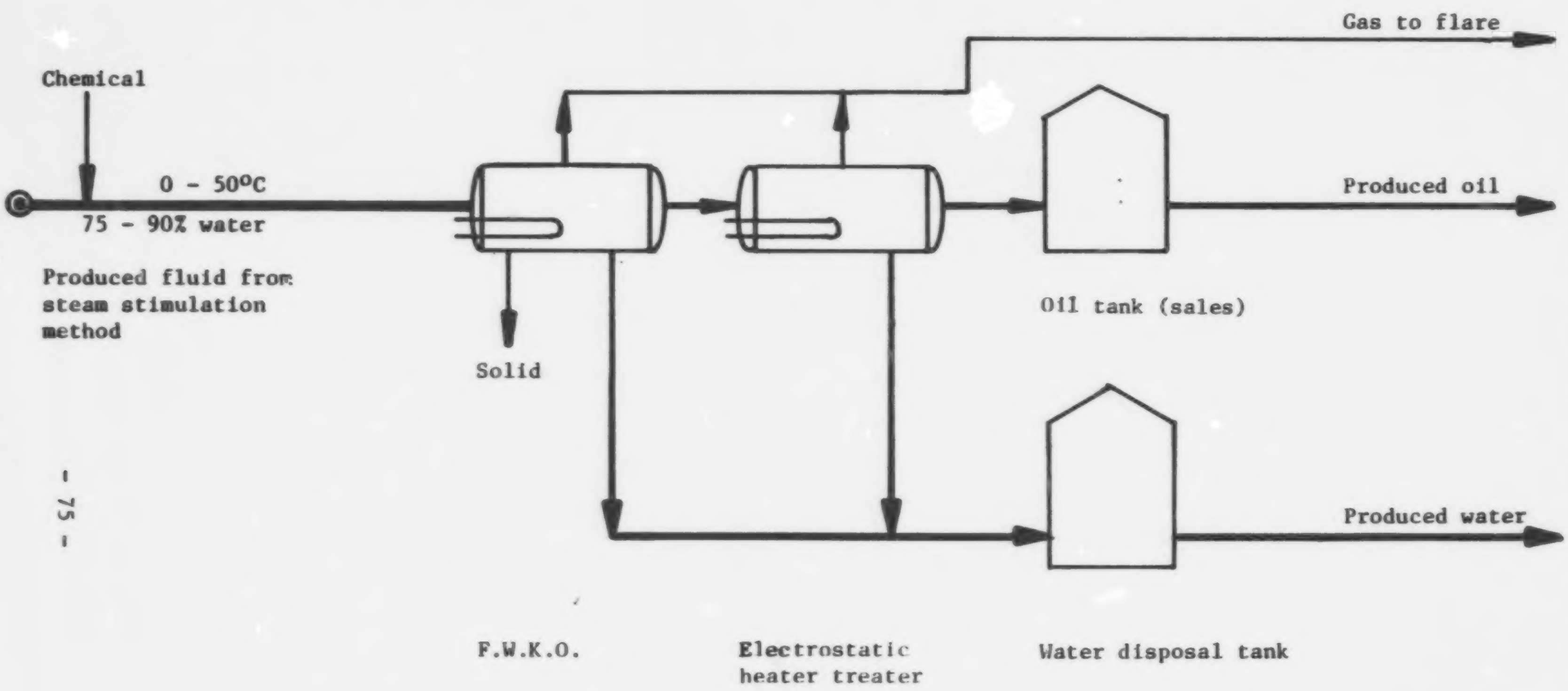


FIGURE 7.7 - TREATMENT FOR HEAVY OIL (°API 10-15) WITH HIGH WATER CONTENT USING F.W.K.O. AND ELECTROSATIC HEATER TREATER

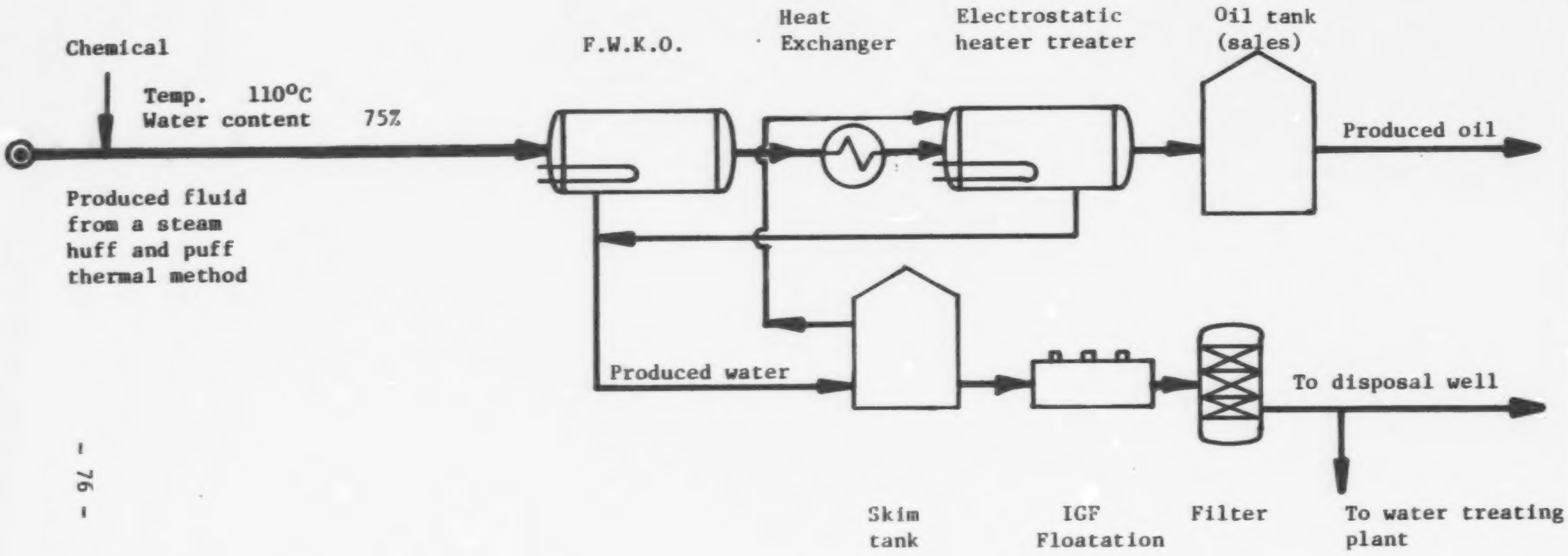


FIGURE 7.8 – TREATMENT FOR HEAVY OIL EMULSION USING GRAVITY SEPARATION AND ELECTROSTATIC HEATER TREATER

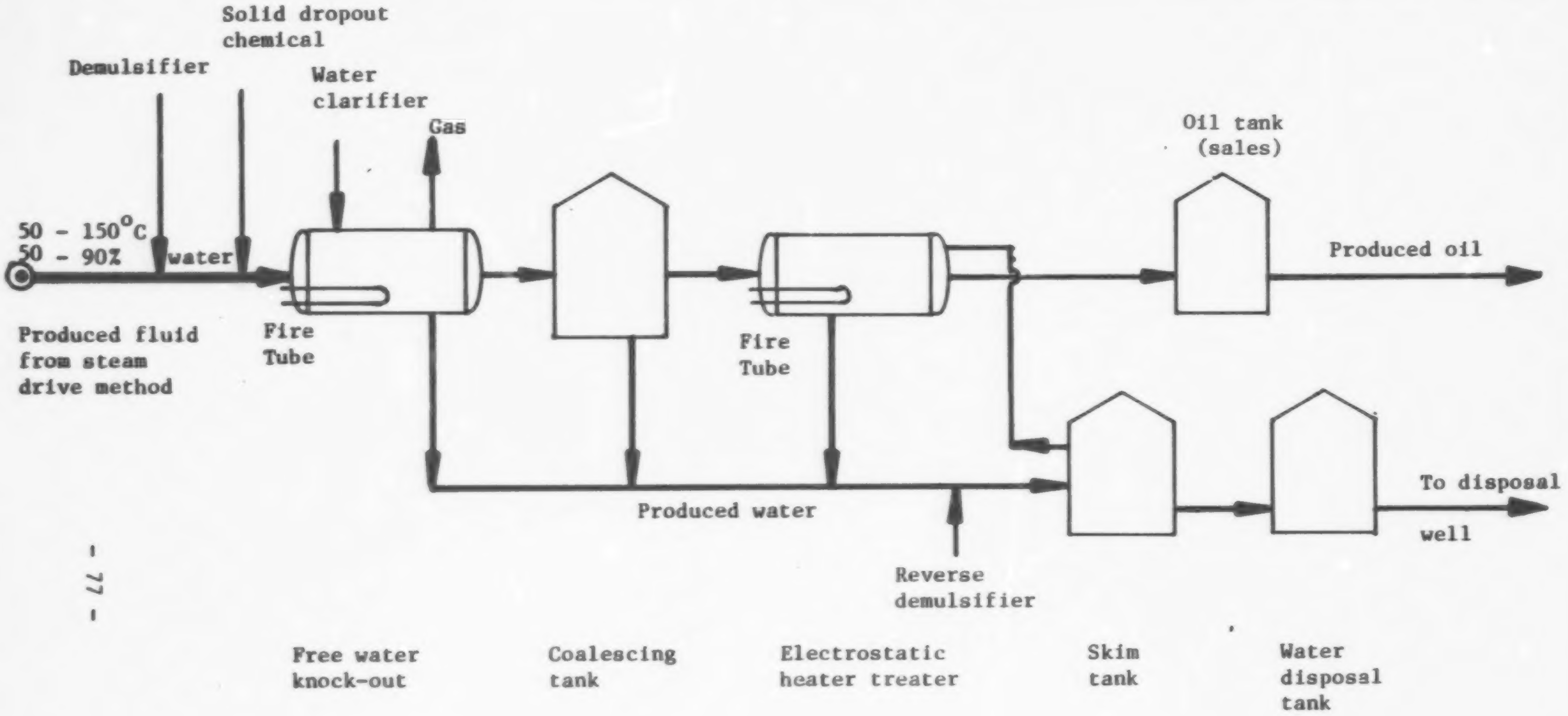


FIGURE 7.9 - TREATMENT FOR HEAVY OIL (°API 10-12) USING GRAVITY SEPARATION AND ELECTROSTATIC HEATER TREATER (WITH CHEMICALS)

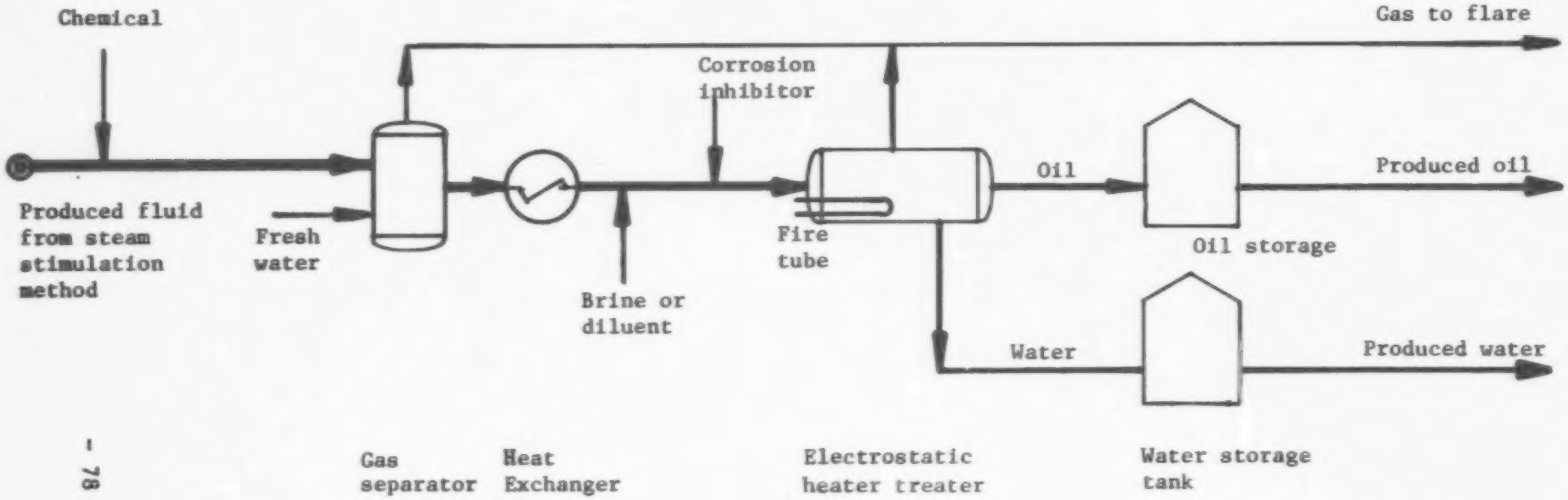


FIGURE 7.10 - TREATMENT FOR BITUMEN (°API 6-10) WITH FRESH WATER AND BRINE OR DILUENT USING ELECTROSTATIC HEATER TREATER

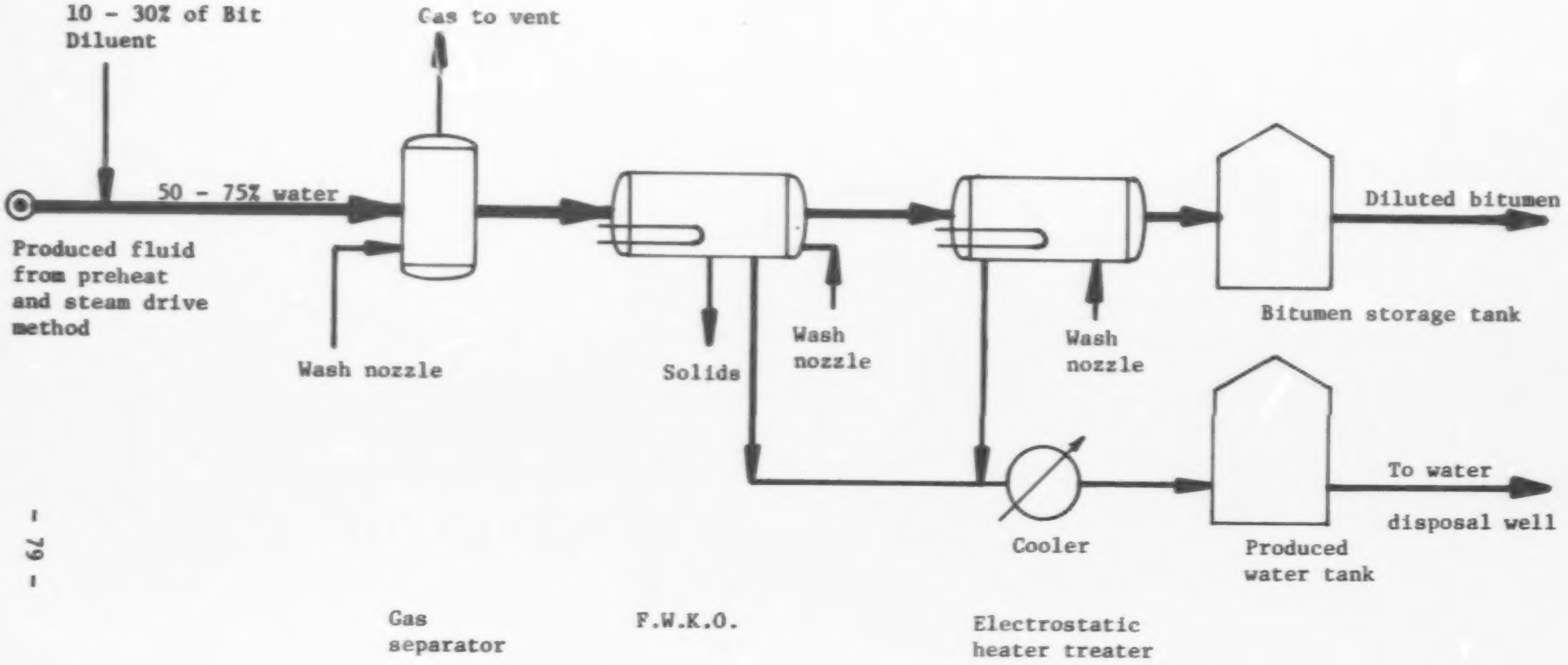


FIGURE 7.11 - TREATMENT FOR DILUTED ATHABASCA BITUMEN (°API 10-12)

7.0 CLASSIFICATION OF COMMERCIAL TREATING METHODS (cont'd)

- Group II - Thermo-Electrostatic Treater (cont'd)

An electrostatic field is sometimes used in FWKO where produced oil is passing through an electrostatic field.

- Group III - Dilution in Combined Methods

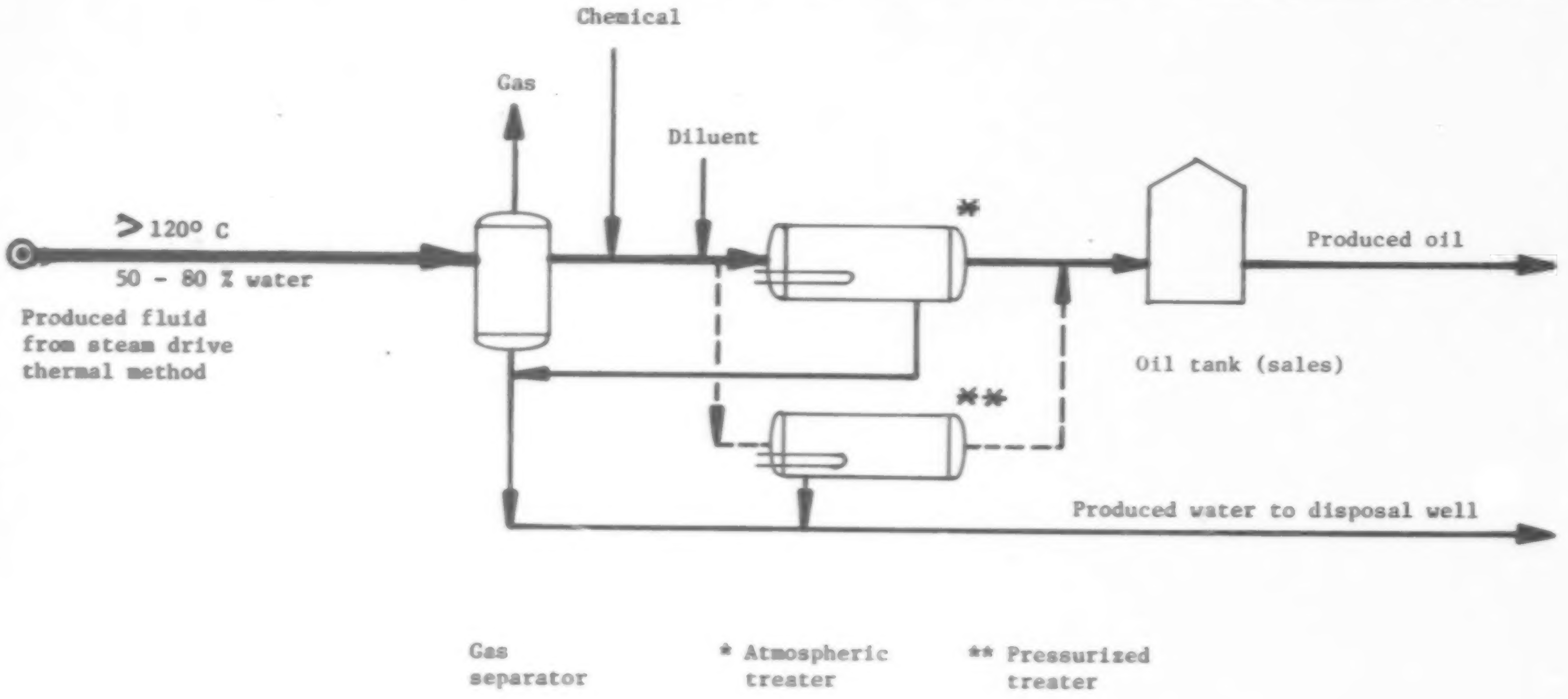
An improvement has been made in separation of low API oils and water from emulsions by using diluent in separation systems. In these systems, produced fluid may be diluted before or during the emulsion treatment.

The systems consists of chemical treatment, gravity separation, heating and an electrostatic field in which the oil and/or water phases are diluted by diluent and fresh water. Light hydrocarbons (condensates) Naptha and recycled oils (from skimmed oil or produced oil) are used to lower the viscosity of the oil or absorb the suspended oil droplets, entering into the oil phase.

Ten to fifteen percent of an 55-60 API light hydrocarbon and up to twenty percent liquid by volume of oil have been used in various oil fields.

Low °API, (10-14) heavy oil and tar sand bitumen recovered in steam flood, with low initial temperature and high water content, (70-80%) have been treated in these systems more efficiently than other methods without the use of diluent.

Typical versions of this system are shown in Figures 7.12 and 7.13. Figure 7.12 shows the use of diluent in an atmospheric and a pressurized treater in a system. Figure 7.13 shows the use of different types of diluents in a system.



7.12 - TREATMENT FOR DILUTED ATHABASCA BITUMEN (°API 12-14)

* for general use
** for tight emulsions
and tests

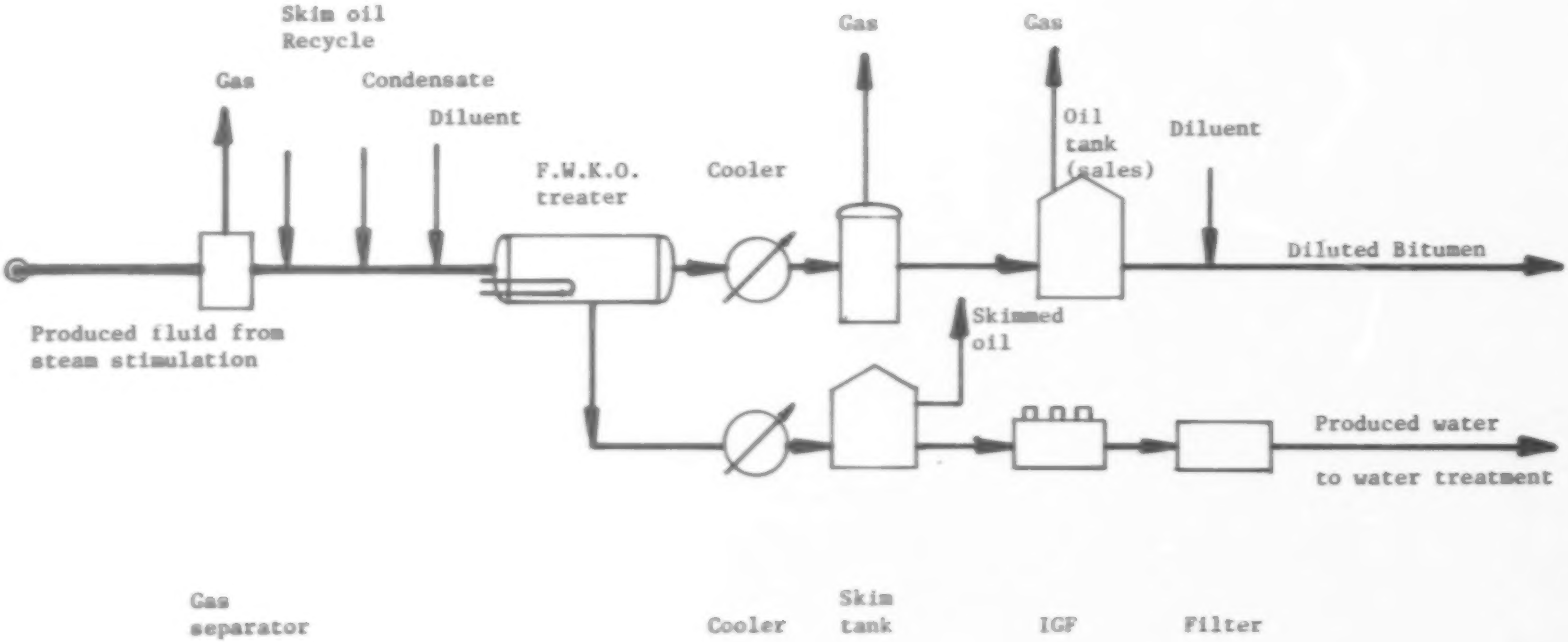


FIGURE 7.13 - TREATMENT FOR DILUTED BITUMEN WITH SKIMMED OIL, CONDENSATE AND DILUENT

- Group IV - High Heating Treating

To break the tight emulsions, a combination of techniques are used. These include chemical treatment, gravity separation, dilution and electrostatic treaters. These methods may not be efficient in cases of very tight emulsions. That is why high temperature vacuum distillation, or atmospheric evaporation has been used.

High temperature techniques have been developed in various forms by different oil companies. These methods are used where the heater treaters and electrostatic treaters have failed to treat tight emulsions.

High temperature treating systems are generally used at the final stage, where water and organic vapours are taken from the top and oil and solids from the side and bottom of the vessel. Oil in this system is completely dehydrated. These methods are used without the heater treater and electrostatic treaters.

A number of modified versions of high temperature techniques have been developed and many are being used by oil companies.

High temperature techniques are used in reduced pressure (in vacuum towers) where oil products are produced at site.

Fig. 7.14 shows the use of **an evaporation system** for dehydration of the produced oil.

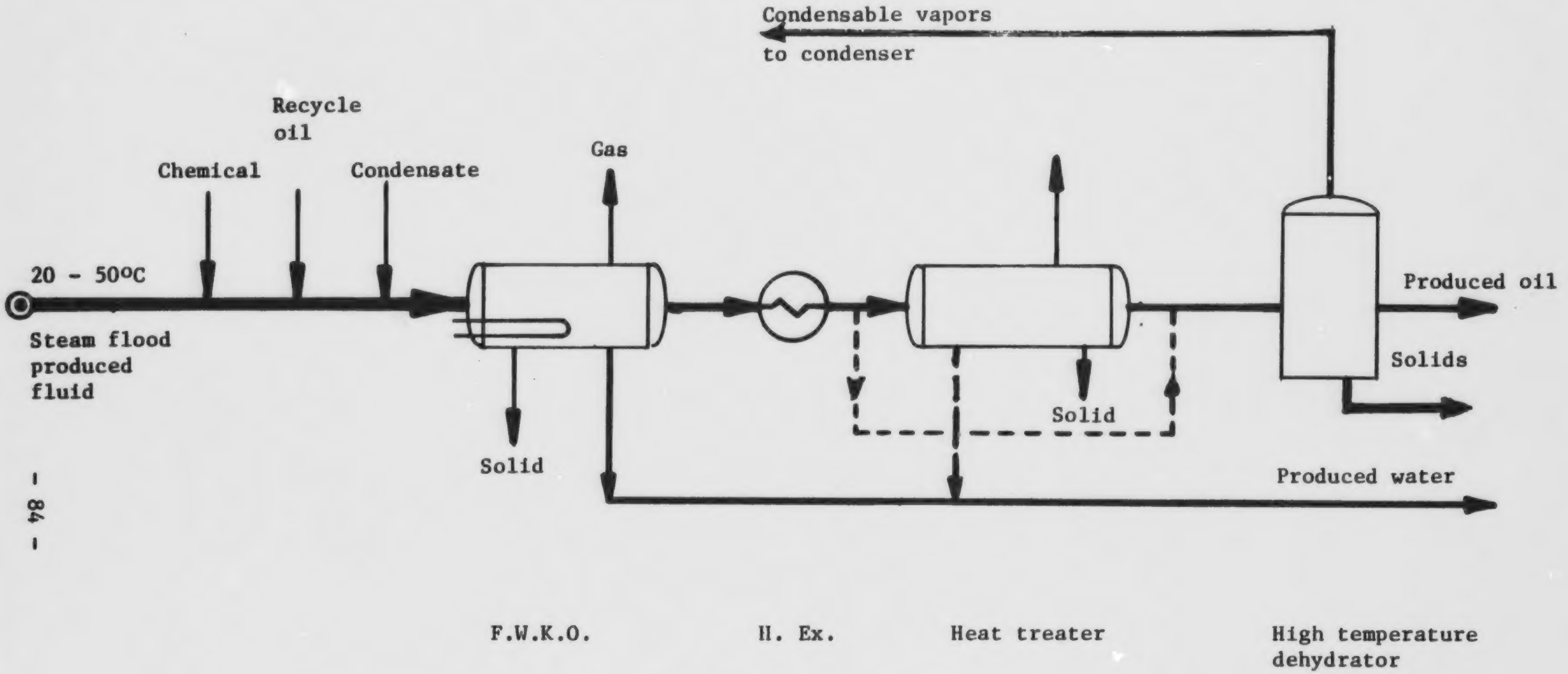


FIGURE 7.14 - HIGH TEMPERATURE DEHYDRATOR TREATMENT
USING DILUENT AND RECYCLE OIL

8.0 REVIEW, EVALUATION AND COMPARISON OF METHODS FOR EMULSION TREATMENT

General

In heavy oil and tar sand bitumen recovery with in-situ thermal methods, the characteristics of the produced fluids vary from well to well in the same area. This is also true for a well operating at different times.

Produced fluid may contain gas, free water, free oil, oil/water emulsion, water/oil emulsion, soluble solids and suspended solids, associated with organic compounds.

The percentage of the constituents present varies. The water content in the produced fluid can be as large as 90% in steam thermal methods and as low as 5% in combustion methods.

The stability of the emulsions in the produced fluids also varies. It is higher in combustion recovery method for low °API oils and lower in steam recovery methods.

8.1 Factors affecting the treatment of these fluids are:

- Type of Oil

°API gravity of the oil or bitumen directly affects the treating conditions. Lower °API needs higher temperature for treatment for lower throughput compared to high °API gravity oil with higher throughput. A maximum capacity curve is prepared by treater suppliers, in which the working capacity for an oil with °API 36, would be about two times (800 B/D) that for a 16°API oil (400 B/D). The treater maximum capacity against degree of °API is shown in Figure 8.1.

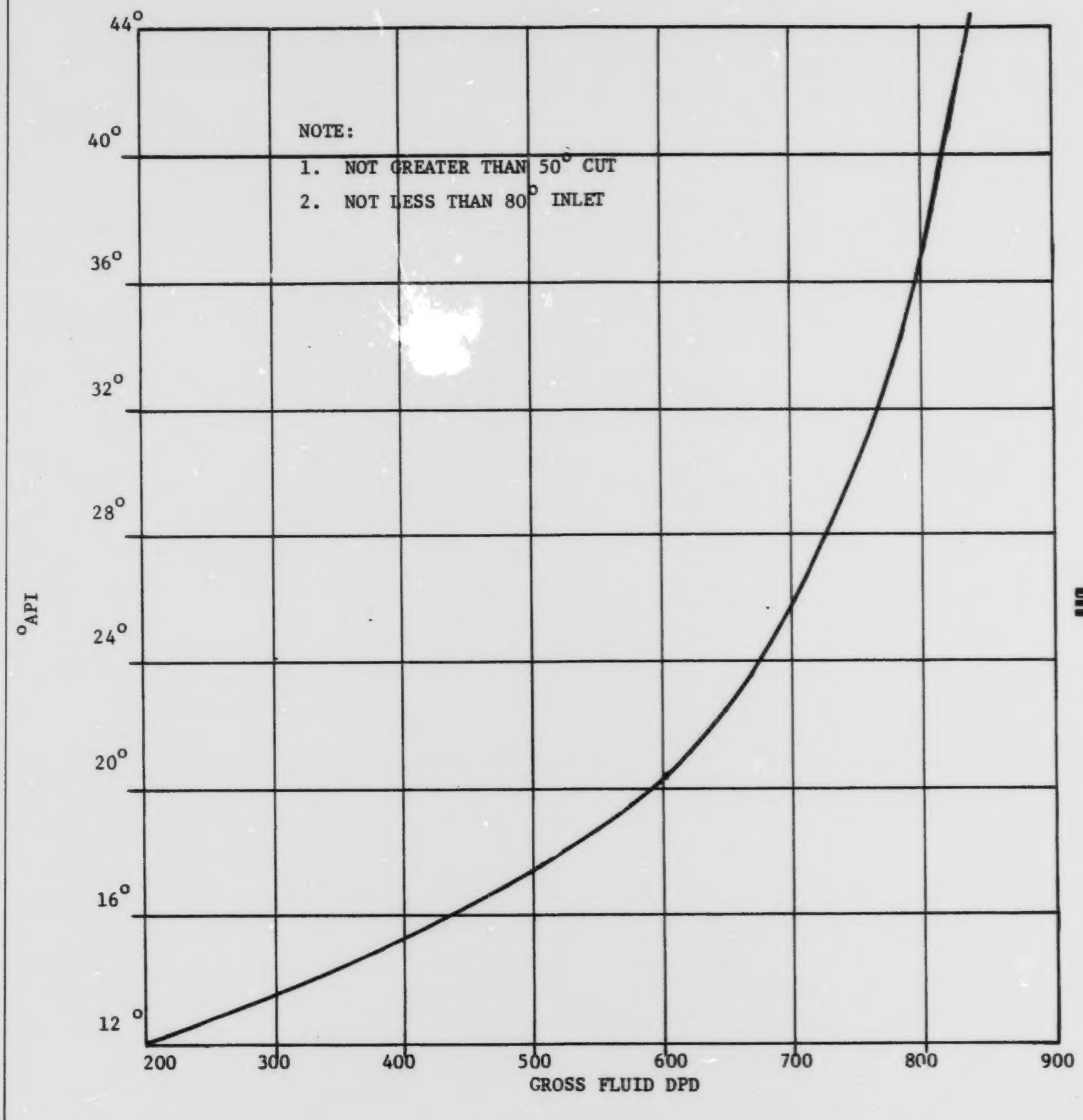


FIGURE 8.1 – TREATER MAXIMUM CAPACITY CURVE

8.1 Factors affecting the treatment of these fluids: (cont'd)

- Type of Oil (cont'd)

Problems have been encountered also in the treatment of low°API oil or bitumen emulsions. These problems have been encountered not only because of low difference between the specific gravity of oil and water but also because of migration of heavy oil end fraction associated with fine minerals entering into the water-oil interface.

This results in the creation of tight emulsions which are difficult to break.

To overcome this problem, diluent and heat have been used to reduce the viscosity of the oil and increase the°API gravity to facilitate the oil/water separation.

- Stability of Emulsions

Stability of the emulsions is directly related to the square of the radius of the dispersed droplets.

The droplet size larger than 60 microns in diameter may be separated in gravity separation vessels or may be separated by passing them through a porous media, or using a centrifuge.

More stable emulsions with a diameter less than 60 microns are tight emulsions. These emulsions will not be broken easily unless a combination of chemical and heat treatment is used.

Very stable emulsions with a diameter of less than 0.1 microns, containing water and fine solids may stand in suspension forever

8.0 REVIEW, EVALUATION AND COMPARISON OF METHODS FOR EMULSION TREATMENT (cont'd)

8.1 Factors affecting the treatment of these fluids: (cont'd)

- Stability of Emulsions (cont'd)

by Brownian motion. They may also be electrically charged due to dissolved ions and the droplets repulse each other and will not coalesce into large droplets. As the droplet size becomes smaller, the total surface area will be increased and a larger number of water droplets will be in contact with a large number of oil droplets. In this case, it is difficult to create coalescence between the water droplets to produce large water drops.

- Viscosity of the Oil

Viscosity of the oil is also a factor affecting settling or separation of water from the oil phase. Higher viscosity results in higher settling time and lower viscosity speeds up the settling of water.

To overcome this, viscosity of the oil is reduced by the addition of diluent or heating the emulsion.

Viscosity of emulsions can be expressed, relative to the viscosity of water, as a function of the concentration of the dispersed phase. This relationship ends as the concentration of the dispersed phase oil reaches a level where the emulsion inverts and becomes water-in-oil emulsion.

The viscosity of an O/W emulsion, in general, will be close to water viscosity. That is why the O/W flows easier than oil itself, at the same temperature.

8.1 Factors affecting the treatment of these fluids: (cont'd)

- Viscosity of the Oil (cont'd)

The droplet size of dispersed phase plays an important role on its flow characteristics, and on its pore passage. The smaller particle size passes easier and sooner than larger ones, therefore, produced fluid in emulsion state, which is brought out of the ground, are of the low droplet size and are stable emulsions.

- Method of Recovery

Experience has shown that there is a marked difference in the result of the treatment of the emulsion obtained from the same pool in different thermal methods.

Less problems have been experienced with the treatment-by-steam method of recoveries than with combustion and fire flood methods.

Generally problems have been experienced with fire flood emulsions. However, in a specific case, emulsion produced by a combustion technique was characterized by special problems. In this case, 25% asphaltene had precipitated as sludge. As the facilities were not available to handle such sludge, the well had been plugged.

Emulsions obtained in a steam huff and puff and cyclic steam thermal methods containing large amounts of water, had not produced such a type of sludge and the breaking of the emulsions was carried out in present commercial separating systems.

8.1 Factors affecting the treatment of these fluids: (cont'd)

- Application of Chemicals

Produced fluids obtained from in-situ thermal methods can not be effectively treated in a conventional treating process. A combination of treating processes are used for a better separation. These processes include thermo-physico chemical and thermo-electrical processes.

Chemicals are used in most of the treating systems. This includes demulsifiers, reverse demulsifiers, solid dropping chemicals and water clarifiers. A corrosion inhibitor is also used for the equipment protection against corrosion.

Mixing, dosage and temperature are the important factors in the application of chemicals in treatment of the emulsions.

In the oil recovery from in-situ methods, there is one thing in common; that is, production of very stable emulsions which are difficult to be treated. This is due to the existence of natural sludges and fine mineral solids. Treatment of these emulsions will not be efficient using only one demulsifier as a number of factors are affecting their stability.

These factors are:

- The ^{o}API of the oil has a direct effect on the stability of the emulsion; as with higher viscosity more stable emulsion will be obtained and chemicals cannot be mixed with viscous oils.
- Aging affects the separation of the emulsion. As the time passes, surfactants create a complete film around the suspended droplets and more chemicals are needed to rupture these films.

8.0 REVIEW, EVALUATION AND COMPARISON OF METHODS FOR EMULSION TREATMENT (cont'd)

8.1 Factors affecting the treatment of these fluids: (cont'd)

- Application of Chemicals (cont'd)

  Chemical properties and corrosiveness of an oil emulsion has a negative effect on the addition of a demulsifier. It may react with the chemicals and additional surfactants may be needed to treat the emulsion.

To break an emulsion with chemicals, a sample of emulsion has to be tested first to find out the suitable chemicals. These chemicals are:

- Demulsifiers (such as non-ironic surfactant blends)

  Generally used in the well-head before gravity separation and/or treatment to permit a better and proper mixing of chemicals with the produced fluid.

- Solid Dropping Chemicals (wetting agent - i.e. cationic surfactants)

  These chemicals as wetting agents are used before separating tanks, FWKO, and/or a settling basin.

- Reverse Emulsion Demulsifiers (high M.W. cationic polyacryamide)

  Used during treating but before heater treater.

- Water Clarifiers (or sludge removers such as sulfonates)

  Used before skim tanks where water has to be clarified from oil.

- Corrosion Inhibitors

  Generally used before the high temperature treating step.

8.0 REVIEW, EVALUATION AND COMPARISON OF METHODS FOR EMULSION TREATMENT (cont'd)

8.1 Factors affecting the treatment of these fluids: (cont'd)

- Application of Chemicals (cont'd)

The aforementioned illustrates the use of chemicals in a treating unit. One or more chemicals may be used at a selected location. Chemicals which have been used by oil companies and are recommended by chemical suppliers by their code names are given in Table 8.1.

The type and dosage of chemicals are selected after a bottle test for each produced fluid. A chemical which is effective in one case may not be effective in the other. Chemicals have also been classified according to their applications for steam floods and fire floods by the suppliers of chemicals in their literature.

In some of the oil field treating plants, the chemicals may not be used as the separation of emulsions is carried out by heating.

8.0 REVIEW, EVALUATION AND COMPARISON OF METHODS FOR EMULSION TREATMENT (cont'd)

8.2 Review of Treating Methods

The simplest process for treating emulsions in the oil field is to pass the chemically pretreated fluid through a series of separating or settling tanks at a suitable treating temperature. In this process, the oil phase is separated from the top of the vessels and produced water is collected and combined from the bottom of the vessels and is sent to the disposal wells or effluent treating units.

Chemical treatment and heating are used to facilitate the oil and water separation by reducing the settling time.

In the separating vessels, speed is not too important and the chemicals have enough time to react with the reactive compounds in the fluids. The water-oil interface is not important as when the water is disposed from the bottom of the vessels, the interface will remain at the bottom of the tank and will not interfere with the produced oil quality.

These vessels provide sufficient time to allow all of the water to settle in a quiet residence. Viscosity of the oil and droplet size of the water are the factors affecting the separation of oil and water.

In this process, a satisfactory treatment is achieved by heating the fluid in a moderate temperature with adequate time for settling. This causes destabilizing of the materials with low boiling points which are present in a solid state in the fluid. Moderate heating on the other hand increases the difference between the specific gravity of the oil and water and reduced the viscosity of the oil. Reduction of viscosity will result in an increase in the rate of fall of the water droplets and reduce the settling time.

8.2 Review of Treating Methods (cont'd)

The time of separation in these systems is high. To reduce the time of separation, equipment such as free-water-knock-out (FWKO) and heater treaters are used. Where space and time are limiting factors, these vessels are used to meet the same requirements of separation in a shorter time.

Free-water-knock-out is a separating vessel with quiet time. This may cause excessive water delivery in the oil because of turbulent flow in the vessel. Average recommended retention time for FWKO is 5 to 10 minutes for a fluid temperature of 38°C.

The application of FWKO in the treatment of the chemically treated produced fluids at low temperature (30°C) and high water content (up to 80%) allows the separation of a large amount of water without heating. This allows the selection of a smaller size heater treater for further treatment of the fluid.

On the other hand, FWKO is generally equipped with a U-shaped gas fired heater to maintain required treating temperature where produced fluid temperature is low.

In this process, stable emulsion cannot be broken and a part of water will remain in oil. This creates a serious problem in the treatment of oil/water interface. This problem has been solved for high°API crude oil by using heater treaters. Heater treaters have been developed to provide gas,oil,water and solid separation from heavy oil and bitumen produced fluids. Heater treaters are designed horizontally and vertically and are equipped with fire tubes. Heater treaters are operated in a temperature range of 80 to 95°C at atmospheric pressure. As the characteristics of the produced fluids change, an atmospheric heater treater may not be efficient in the treatment of tight emulsions.

8.2 Review of Treating Methods (cont'd)

Pressurized heater treaters are developed to treat the fluid above the boiling point of the water. The produced fluids which could not be treated in an atmospheric treater is transferred to a pressurized treater, operating at a temperature up to 121°C and at a pressure of .52 MPa. In the latter system, only the oil phase that separated from produced fluid is treated.

The heater treaters occupy less volume than a series of separating tanks. Therefore, less time for settlement and separation of water is required. Speed is important, because the treatment time is shortened. Suitable chemicals should be used to minimize the problem of solid collection in the oil-water phase.

In horizontal heater treaters, higher feed rate is used as a larger interface area and lower fluid depth are required. Horizontal heater treater can tolerate only a thin interface layer and it is necessary to control this level accurately.

Water-oil interface in a vertical heater treater has more space for adjustment but the feed rate will be lower than a horizontal one.

Due to high temperature (95° - 120°C) and the corrosiveness of some of the fluids, corrosion inhibitor and/or corrosion resistant metals are used.

The retention time, in general, is designed to be 20 hrs for oil and 2 days for water in an atmospheric heater treater.

8.0 REVIEW, EVALUATION AND COMPARISON OF METHODS FOR EMULSION TREATMENT (cont'd)

8.2 Review of Treating Methods (cont'd)

In the pressurized heater treater, the retention time is 6 to 8 hours for oil and 2 hours for water in the same design criteria. Comparing these two, clear water may be obtained in atmospheric treater and cleaner oil obtained from the pressurized treater.

A process combining chemical, gravity separation and heating has been used by most of the developers, where produced water is injected back to the injection well. This minimizes the water/oil emulsion in the produced oil and aids in the separation of clean oil, yielding an oil of the required specification, 0.5 max BS&W. Some problems have been encountered with this process. These are:

- Changes in the characteristics of produced fluids which creates operation problems.
- The small difference between the specific gravity of oil and water, results in low efficiency in separation and control of the water level in the separation tanks.
- The existence of very fine solids in the oil/water interface, observed as a sludge pool, specially for low °API oils, the mixture has proven to be difficult to separate.
- Small water droplets have resulted in the production of stable emulsions. This creates problems in coalescence of water droplets in the treating systems.

8.2 Review of Treating Methods (cont'd)

These problems are overcome by using other techniques which maintain dehydration and create sharper separation. Solids and salty water (conductive particles) are electrically charged and coalesce in an electrostatic field. The coalescing of small droplets results in larger droplets which are then separated by gravity. This has been used to separate small amounts of water that exist in the produced oil.

Electrostatic equipment is operated at high voltage (12,000 - 30,000 volts) and at temperatures between 110^{o} to $120^{o}C$. It is generally equipped with a U-shaped fire tube. Fluid enters the top of the treater, where it is heated. Gas is removed at the warmest part of the treater and gas free oil flows through an electrical coalescing section with a uniform flow. Clean oil is taken from the top and the coalesced drops of water are dispersed in the oil. This is accomplished by the high-voltage electrical field. Since all the water droplets are electrically charged, they will coalesce and become large droplets.

Stock's law indicates that for any oil/water system, the settling rate of water will be increased by:

- Reduction of viscosity and/or
- Increase of droplet size

A packaged system of heating plus an electrostatic field has been developed to meet the above requirements. Heating lowers the viscosity of the oil and reduces the settling time of the water droplets; the decrease in the viscosity would be greater than the decrease in density difference.

8.0 REVIEW, EVALUATION AND COMPARISON OF METHODS FOR EMULSION TREATMENT (cont'd)

8.2 Review of Treating Methods (cont'd)

Reduction of viscosity increases the dehydration efficiency linearly, while increase in droplet size increases settling rate exponentially. An increase in droplet size can be achieved by the application of an electrostatic field in which two immiscible liquids, one conductive and one non-conductive, pass through a high intensity electric field. The conductive liquid droplets coalesce and form large droplets which settle faster than in normal treating methods.

Since the electrostatic field causes the coalescence of water droplets, the application of this equipment improves the dehydration of the oil remarkably.

Greater voltage potential has given a better dehydration but it is limited because of excessive power consumption and high capital cost. The optimum operating voltage is obtained by estimating the lowest required voltage for a relatively high efficiency rate.

Electrostatic field is created between two electrodes, in the coalescing section of the vessel, charged electrodes and ground electrodes in AC system or positive and negative electrodes in DC system . Sometimes both systems are used in a package, to create low and high gradient electrostatic fields.

When the fluid is passing through the electrostatic field, water droplets are charged differently and coalescing response is very rapid.

The coalescence of small water droplets can be achieved in a short time in the electrostatic field process, by using a vessel with optimum retention time. This is nearly impossible to carry out in physico-chemical processes.

The retention time in an electrostatic treater is an important factor for a good separation. This is obtained by selection of a larger size diameter vessel. The larger diameter with the same cross section area of a vessel has a higher retention time. Therefore, in the case of a low°API oil or bitumen, a vessel with a large diameter is used as compared with those used for high°API crudes.

Some problems have been encountered in electrical conductivity of oil (in presence of water) and change of oil characteristics which limits the application of an electrostatic field:

- Temperature is a limiting factor in the application of the electrostatic treater because insulations are effected when temperatures of operation exceeds 150°C.
- The retention time in electrostatic treaters is the same as in a pressurized heater treater of the same size. It would be 68 hrs for oil and 2 hrs for water in a 10' x 50' heater treater, in the same design criteria.

Dilution is used where a higher difference between specific gravities of oil and water are required or when heat cannot be used for lowering the viscosity.

In this process, low°API oil is diluted by a solvent and the oil viscosity is lowered. The rate of the reduction depends on the type and amount of the solvent, the type of the oil, the percentage of insoluable organic compound and the °API of the oil.

As the viscosity of the oil is reduced, its specific gravity also is lowered resulting in a higher difference between specific gravity of the oil and water.

Lower °API oil or bitumen need a higher amount of solvent or lighter diluent to reach a requirement in the °API limit.

Dilution of water phase using fresh water, or thickening the water phase, has the same effect as diluent on the oil. This increases the difference between specific gravities of oil and water. Dilution is mostly used before treatment to facilitate the separation of free water and solids in the separation process. It is sometimes used during the treatment.

Application of a diluent depends on its availability and its effectiveness in the process. In the treating plant, the condensation of light hydrocarbons collected as condensate is used as a diluent and recycled back to the produced fluid.

Skimmed oil sometimes is used as a diluent. This not only helps to dilute the feed but also prevents the further treatment for skimmed oil.

Diluent sometimes is provided from outside the field. Liquids of light hydrocarbons (with °API 55-60) including naphtha, are used and injected into the production well for low API oils or bitumen.

8.0 REVIEW, EVALUATION AND COMPARISON OF METHODS FOR EMULSION TREATMENT (cont'd)

8.3 Comparison of Separation Methods

In separation of solids, water and oil from produced fluids using chemicals, heat, settling or wash tank and separators, the operating temperature is one of the main factors in the reduction of the settling time for water droplets.

The parameters used in these techniques are interrelated. To change the settling time, either heat or a chemicals must be used. To reduce the temperature, settling time and/or chemicals application must be increased. Time of treatment for a normal emulsion in the above system is about 2 - 7 days.

By changing the temperature and design of the equipment, settling time is reduced from 2 - 7 days to 1 - 5 hours and the separation of oil and water from emulsion is carried out in a shorter time in free water knock-out and heater treater. The temperature can be increased above 100°C by operating the treaters at .24 - .52 MPa pressure for a tighter emulsion.

Free-water-knock-out works as a gravity separating tank, where free water and solids are settled. A heater treater is generally used to treat the oil phase containing oil/water and water in oil and fine solids accumulated in the oil/water interface.

The free water is not necessarily clear water. The characteristics of free water depend on produced fluid properties and desired clarity.

Comparing the thermo-physico chemical process with the thermo-electrostatic process, an additional parameter is added in the system to the latter.

8.3 Comparison of Separation Methods (cont'd)

This parameter is the electrostatic field which causes the coalescence of conductive water droplets in oil to occur in a much shorter time, (a fraction of a second). On the other hand, when the emulsions are tight, produced oil cannot be dehydrated in heater treaters, but it can be separated by the use of electrostatic field in 3 - 5 hrs.

In comparison of the treating processes, the type of oil and method of oil recovery are taken into consideration. Parameters directly affecting the design of the vessels and the settling time are the degree of API of the oil and the type of emulsions. For very tight, low °API, heavy oil or bitumen emulsions which cannot be easily separated, methods based on the difference of specific gravities between oil and water are utilized. The viscosity of the oil can be reduced by heating but because of the high energy consumption its application is limited. Dilution of the oil or water phase has the effect of increasing the °API of the oil thereby facilitating the separation of oil and water.

Heating of the produced oil up to 120° C in the heater treater and the electrostatic treater may not be enough to evaporate the fine water droplets embedded in the oil phase. In cases when the emulsions are very tight and stabilized by very fine solids, heating the oil phase to temperatures between 160° - 165°C at atmospheric pressure and to temperatures between 380° and 400°C at elevated pressure causes the fine water droplets to be evaporated. The oil viscosity at this temperature is lowered to permit the water to escape in the form of vapor. Solids, because of their higher specific gravity, will settle down and separate. A comparison of four separation groups are given in Table 8.1

TABLE 8.1

COMPARISON OF THE FOUR SEPARATION GROUPS

		I	II	III	IV
1-	Chemical Treatment	Used	Used	Used	Used
2-	Gravity Separation	Totally used	Partly used	Partly used	Partly used
	- Space	Large	Medium	Low	Varies
	- Separation time	High	Medium	Medium	Medium
	- Heating energy	Low	Medium	Medium	High
	Heater Treaters	Used	Used	Occasionally used	Used
	Electrostatic treaters	Not used	Used	Occasionally used	Not Used
	Dilution	Not used	Not used	Used	Used
	Evaporation (high temp.)	Not used	Not used	Not used	Used
	Type of oil (°API)	10-18	12-16	8.8-10	6-10
	Treating temperature:				
	- Under atmos. pressure	40-90°C	90-121°C	--------	150°C
	- Under a pressure of .52 MPa max.	90-95°C	90-125°C	88-120°C	-
	Thermal recovery methods mostly used	Steam	Combustion	Steam and/or combustion	Combustion

8.4 Comparison of Equipment used in the Oil Fields

Comparison of the equipment used in the oil fields are given in Table 8.2. This table shows that each class of equipment can be used for a specific type of oil or bitumen emulsion.

The equipment used in the first step of separation are the separator and settling tanks. These vessels are used for emulsions with relatively large droplets, and considerably high difference in specific gravity between oil and water. The settling time is 4 - 7 days. This equipment can be used for high ^{o}API and non-stable emulsions. Time and space are the factors to be taken into consideration in the application of this equipment.

Free water knock-out or other types of separators are generally used in combination with heater treaters where 90% of free water and solids are separated. In FWKO, the oil phase, containing a very small amount of solid and water in the form of a stable emulsion, is treated in the heater treater.

Atmospheric heater treaters have the advantage of higher speed, lower space requirements and better performance. Tighter emulsions could be treated in pressurized heater treaters, at a higher temperature than that used in atmospheric heater treaters.

The water phase obtained from atmospheric heater treaters is generally clean. This is due to the larger rentention time of 2 days for water. In pressurized treaters, produced oil is cleaner compared to atmospheric heater treaters. This is also due to a high retention time for the oil.

TABLE 8.2

COMPARISON OF EQUIPMENT USED FOR TREATMENT OF EMULSIONS IN THE OIL FIELD

	Settling Tanks	Heaters Treaters	Pressurized Heater Treaters	Electrostatic Heater Treaters	Flash Treaters
Temperature ^{o}C	80 - 90	85 - 95	90 - 125	90 - 125	160°C
Pressure MPa	Atmos.	Atmos.	.52 Max	.52 Max	Atmos. or reduced press.
Retention time for:					
Water -	4 - 5 days	2 days	2 hrs	2 hrs	-
Oil -	2 days	2 hrs	6 - 8 hrs	6 - 8 hrs	-
Used for:	Considerable difference in gravity of the oil and water	Normal emulsion	Tight emulsion	Tight emulsion	

8.0 REVIEW, EVALUATION AND COMPARISON OF METHODS FOR EMULSION TREATMENT (cont'd)

8.4 Comparison of Equipment used in the Oil Fields (cont'd)

The electrostatic heater treater is comprised of a pressurized heater treater, with electrostatic field facilities. This system permits the breaking of tight emulsions which could not be broken in a heater treater. The electrostatic treater replaces the heater treater and is used for produced fluid with low water content or produced oil.

Gravity separation is one of the simplest and most effective methods of achieving separation for high°API oil. Dilution of either the oil or water phase creates a larger difference between specific gravity of the oil and water (5-10°API difference) and hence aids in the separation of the phases.

Gravity Separation technique is considered attractive because:

- Separation of oil and water is facilitated by using a diluent.
- Diluents can be regenerated and reused or left in the oil phase, since diluted oil could be transported easier.
- The generated gas in the system would not be lost and may be used as condensate (diluent) in the system.

Tight emulsions which may remain in the oil/water interface and are not affected by dilution may be treated in heater treaters or electrostatic treaters. In this stage, the degree of separation may change due to the nature of the emulsion. Treating an emulsion at higher temperature creates a better chance for breaking it.

8.0 REVIEW, EVALUATION AND COMPARISON OF METHODS FOR EMULSION TREATMENT (cont'd)

8.4 Comparison of Equipment used in the Oil Fields (cont'd)

Chemical treatment is generally costly. It may break the emulsion but it adds new ingredients to the oil and water systems. The addition of new materials in the system, sometimes makes the separation more complicated.

Electrostatic treatment, on the other hand, does not leave any trace in the product and/or the tailings.

Heating, at a high temperature, is used to evaporate water emulsions where traces of minerals are considerable. This is minimized when a vacuum system is used. By-products are produced and trace minerals only remain in the residue. This is generally used in road construction and does not have a serious effect on its application.

Dilution is as effective as heating in facilitating oil/water separation, and has the following advantages:

- Increases the differences between specific gravities of oil and water.
- Thins the organic film around the suspended solids associated with organic compounds.
- Can be regenerated and recycled continuously.
- Can be used in moderate temperatures preventing a loss of high degree API oil.
- Creates flexible operation in obtaining desired °API by changing the ratio of diluent.

Some of the disadvantages are:

- Limited availability of suitable solvents on the site.

8.4 Comparison of Equipment used in the Oil Fields (cont'd)

Some of the disadvantages: (cont'd)

- Additional operation for regeneration and make-up of the diluent.
- Inability to dissolve all the organic compounds due to some of the insoluble solid organics.

Advantages of the application of the Electrostatic Treater:

- Dehydration occurs at a temperature higher than in conventional treaters.
- The application of chemicals is eliminated in some cases.
- Electrostatic treaters can be used where other treating methods fail.
- Treatment by electrostatic treaters has no effect on the products property as it leaves no trace in the separated phases.

Some of the disadvantages are:

- Does not allow rapid change of feed specific gravity or inlet temperature as the treatment will be upset.
- Change of oil/water interface results in off specification products and probably will short circuit where the oil/water interface levels are high.
- Larger size of equipment is necessary for lower API oil and stable emulsions.

9.0 REVIEW OF PRODUCED WATER TREATMENT

In thermal methods, where steam is used in oil or bitumen recovery, the amount of steam needed in thermal recovery would be several times the amount of the recovered oil. In these cases, a large amount of water is used. Where the use of natural water is a limiting factor, produced water or a combination of produced water and a city waste water and/or natural water is treated to prepare an acceptable water quality for utility and steam generation. There are a number of proven technologies for waste water treatment. Three techniques which are being used in the treatment of the produced water in the oil field are given in Figures 9.1 to 9.3. Figure 9.1 shows the flow sheet for treatment of an effluent mixed with sewage water. Figure 9.2 shows a flow sheet of the treatment of a diluted effluent with fresh water and Figure 9.3 shows a flow sheet of a typical water effluent treatment. Details of the treatment of some of these techniques are given in other studies, (28,29,40,41 and 42).

9.1 Treatment of the Produced Water

9.1.1 Produced Water

Produced water generally contains oil, suspended solids and disolved minerals. These constituents are found in the form of very stable emulsions.

Concentration of these constituents in produced water vary in different areas, depending on the recovery and treatment methods of the produced fluids and degree of separation of organic compounds from water.

The treatment of the different produced waters cannot be generalized because of these variations. The water from each location has specific characteristics that must be considered prior to treatment.

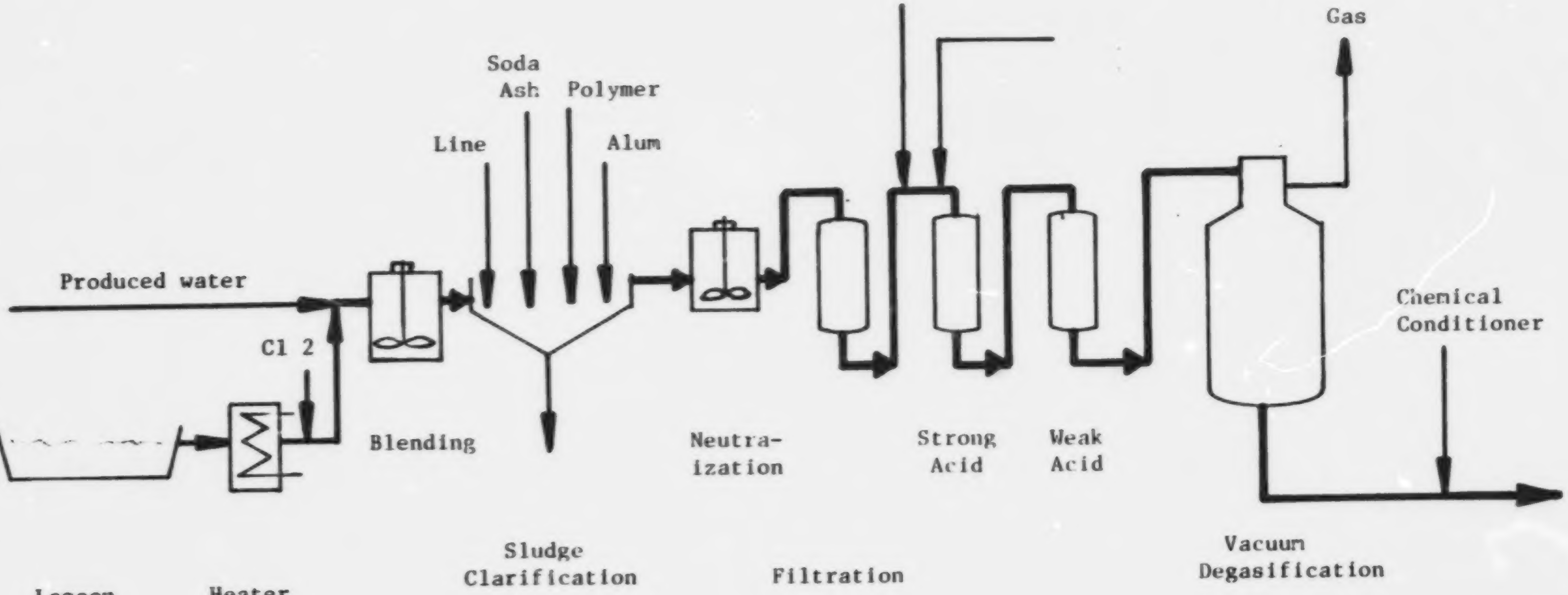


FIGURE 9.1 - TREATMENT OF EFFLUENT DILUTED WITH SEWAGE WATER

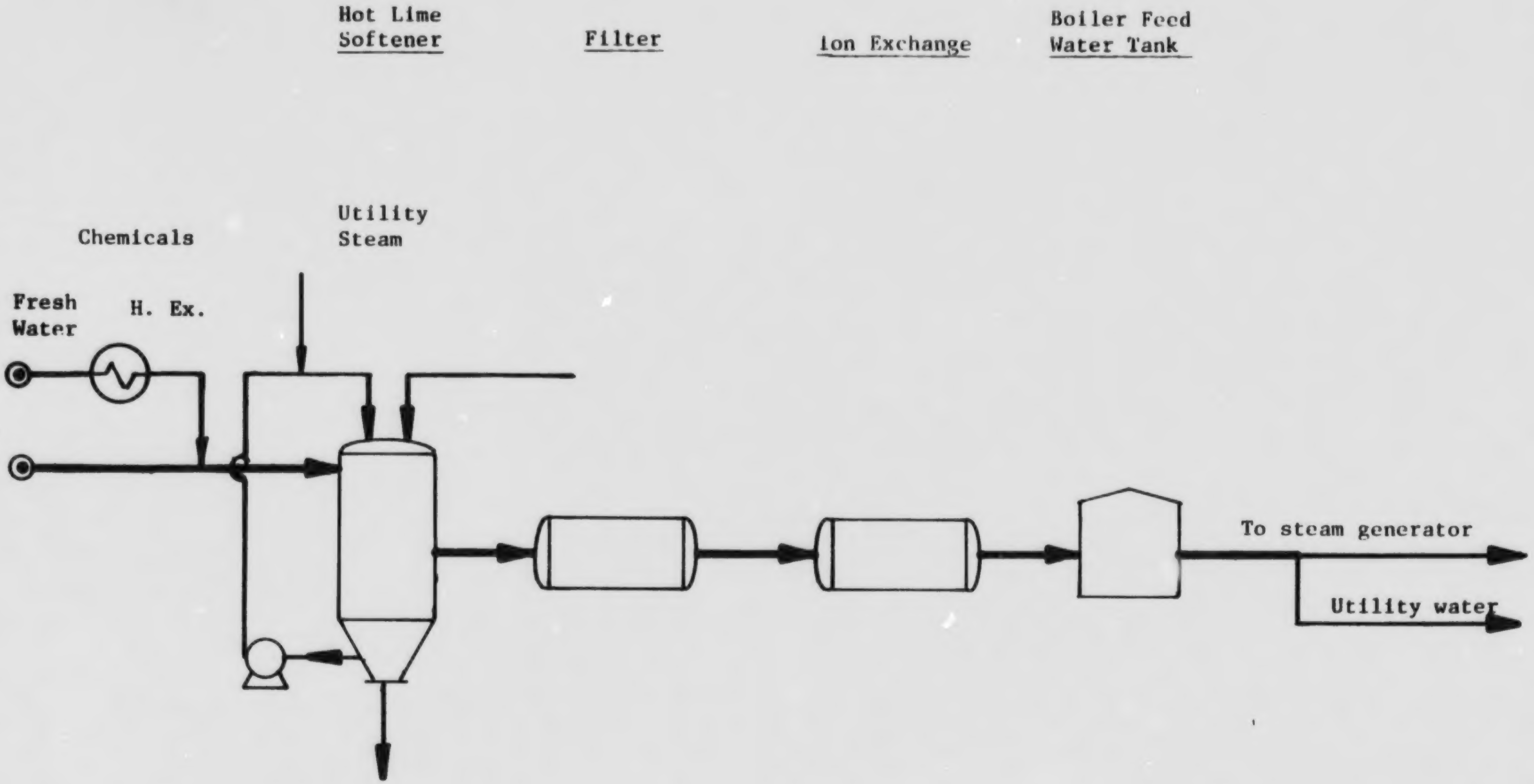


FIGURE 9.2 - TREATMENT OF EFFLUENT DILUTED WITH FRESH WATER

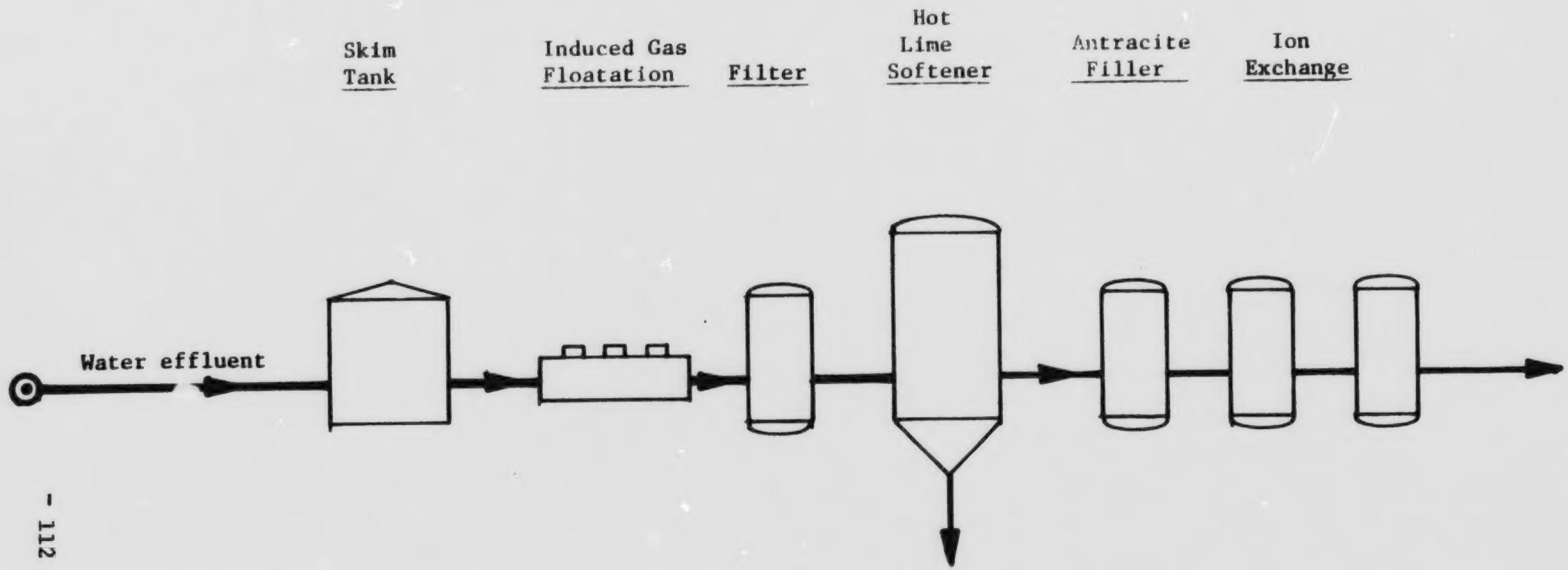


FIGURE 9.3 – TYPICAL WATER EFFLUENT TREATMENT

9.1 Treatment of the Produced Water (cont'd)

9.1.1 Produced Water (cont'd)

Treatment of produced water, obtained in in-situ thermal methods, have been assessed by others (13, 14, 15).

The water treatment, in general, is carried out in three steps:

- Removal of oil and suspended solids
- Removal of silicates and carbonates
- Reduction of hardness

9.2 Review of the Water Treatment Methods

9.2.1 Removal of the oil and Suspended Solids

Oil in the effluent water may be composed of large and fine droplets. Depending on the type of the effluent water, a skim tank is used to separate large droplets of oil. When oil droplets are fine and associated with fine solids, induced gas flotation is used, followed by sedimentation. Chemicals and/or filtration (using diatomaceous earth, sand and single or dual media pressure filters) are used to remove the oil and suspended solids. By this method, the oil content is generally reduced to less than one mg/L in the final stage and suspended solids are also completely removed.

9.2.2 Removal of Solids

When the concentration of solids in water effluent is high, a lime softener method can be used.

9.2.2 Removal of Solids (cont'd)

In this method, on the basis of effluent chemical properties, lime and caustic soda with or without magnesium oxide may be used. In hot lime treatment, the concentration of carbonates and silicates will be less than that in cold lime softening method.

The use of lime softening is more economical when effluent has a high TDS. High temperature of the effluent is desirable if the hot lime softening method is selected.

9.2.3 Water Softening

The application of ion exchange for softening of effluent water, generally is carried out after filtration of the effluent. This is carried out to reduce the cost of regeneration of the resin as a high concentration of impurities deteriorates the resin.

Weak acid cation resins are used for effluents containing high dissolved solids and strong acid cation resins are used for low solids content effluents.

The application of weak acid cation resin ion exchange is costly because of regeneration of chemicals. This is a disadvantage of this system..

Strong acid and weak acid can be used in series as primary softener and polisher. This reduces Ca and Mg concentration to less than 5 mg/kg total hardness. Resins in this method are less affected by salinity.

9.2.3 Water Softening (cont'd)

Effluent waters with high dissolved solids are sometimes treated with further gas flotation, using nitrogen in a gas blanket system.

The advantage of this system compared to hot lime softening is that the chemical used is less corrosive. The load on the ion exchange resin will be increased for obtaining an acceptable water quality.

Water for irrigation,utility and purposes other than steam generation can be produced by using induced gas flotation (IGF), instead of filtration and ion exchange at the final stage of the treatment.

Another method which is used for the treatment of the effluents is to dilute the effluent with natural water or to mix the effluent with a semi-treated sewage water before treatment.

Effluents which generally have high dissolved solids content and low oil content are treated in this method. Two examples of mixing of effluent with sewage water and addition of fresh water to effluent are shown in Tables 9.1 and 9.2.

Where natural water or sewage water is used, chlorination is required to prevent biological growth. This will bring dechlorination into the process. This is necessary to neutralize chlorine to avoid any damage to ion exchange resins. A typical water treating system of effluent diluted with fresh water is given in Figure 9.2.

TABLE 9.1
RAW PRODUCED WATER PROPERTIES

Oil content mg/L	100-12000
TDS mg/L	844-22000
Cl	48-12500
Suspended solids mg/L	5- 315
SiO_2	125- 250
Na	215- 8000
Fe	0.1- .8
pH	7.5-8.3

TABLE 9.2
TREATED WATER PROPERTIES

	Max. concentration
Oil content mg/L	1.0
Hardness mg/L	0.1
TDS mg/L	8000
Chlorine	2000
Silica	50
pH	7.5

Data extracted from references (38,39, and 40)

9.0 REVIEW OF PRODUCED WATER TREATMENT (cont'd)

9.2.3 Water Softening (cont'd)

The chemicals used in water treatment are highly corrosive and operation is generally carried out in absence of oxygen, using gas blankets. Safety is one of the major considerations in this operation.

SECTION III

PILOT PLANT AND EXPERIMENTAL WORK

10.0 SAMPLING, COLLECTION AND CHARACTERIZATION

10.1 Sampling and Collection

A number of heavy oil and bitumen oil producers were approached and a preliminary assessment of the characteristics of their products was made. Based on these assessments, emulsions produced. by an oil company in Alberta, herein called "OCA",was selected. Their emulsions represent the typical emulsions being currently produced in Canada requiring the application of various treatment methods. This anonymity was given to the said company in order to keep the source of the emulsion samples confidential.

10.2 Sample Collection

Two samples identified as A & B were obtained in heavy oil recovery by the thermal method from the pilot plant located in northeast Alberta. These were virgin samples and had not been treated chemically. One drum of each produced fluid samples A & B was obtained from the plant during special non-production runs during the last week of June, 1984. The samples were collected from 2 wells before any processing on the same day at the same time. The samples were shipped to C.E. NATCO, Tulsa, Oklahoma for pilot plant tests.

10.3 Characterization of the Samples

Two samples identified as A & B, of the produced fluids from "OCA", North Eastern Alberta Heavy Oil Thermal Project were characterized. The BS & W of the produced fluids was obtained using ASTM D-96-73 test procedure. This essentially consists of a sample 50/50 of emulsion and xylene at 60°C, and the mixture centrifuged for five minutes at 2000 RPM. The BS &W by volume for the samples A and B was found to be 55 and 45 volume percentage respectively.

11.0 DESCRIPTION OF THE PILOT PLANT FACILITIES AND TEST PROCEDURES

11.1 Pilot Plant Facilities

C.E. NATCO, a division of Combustion Engineering Inc., Tulsa, Oklahoma, has a pilot plant test facility in which chemical, heating and electrostatic field treatment may be carried out.

This pilot plant consists of an assembly of:

- variable speed mixer
- variable speed pump
- Line heater
- No. 1 vessel which can be used as an A.C. electrostatic treater and/or a Free Water Knock-Out .
- No. 2 vessel fitted with an AC/DC dual polarity electrostatic coalescer.
- Interface controller (Conductive type probes)
- Solonoid valve for water discharge.
- Blow down tank (for produced oil receiver)
- Underground oil storage tank.

A simplified diagram of the facility is shown in Figure 11.1 and a photograph of the pilot plant is given in Diagram 11.1.

11.2 Test Procedure

Raw sample is first mixed to be homogenous and a representative portion is then centrifuged to find out the percentage of the BS & W.

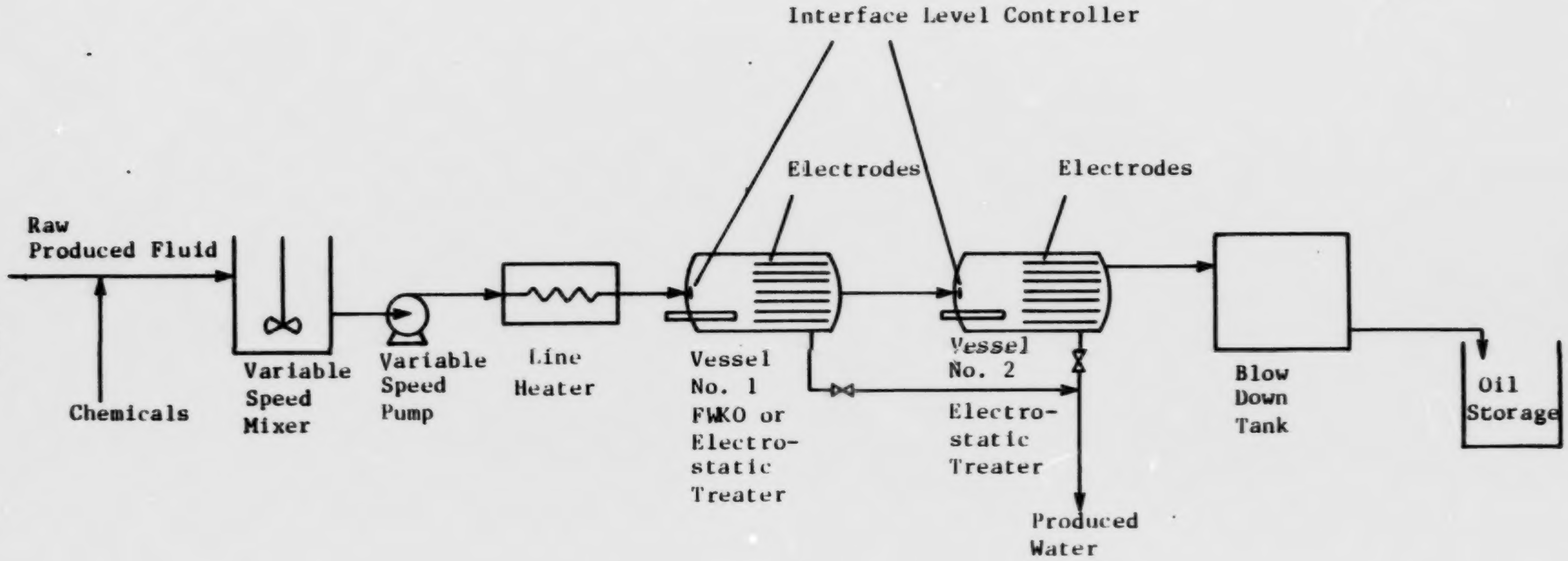


FIGURE 11.1 - NATCO PILOT PLANT FACILITIES

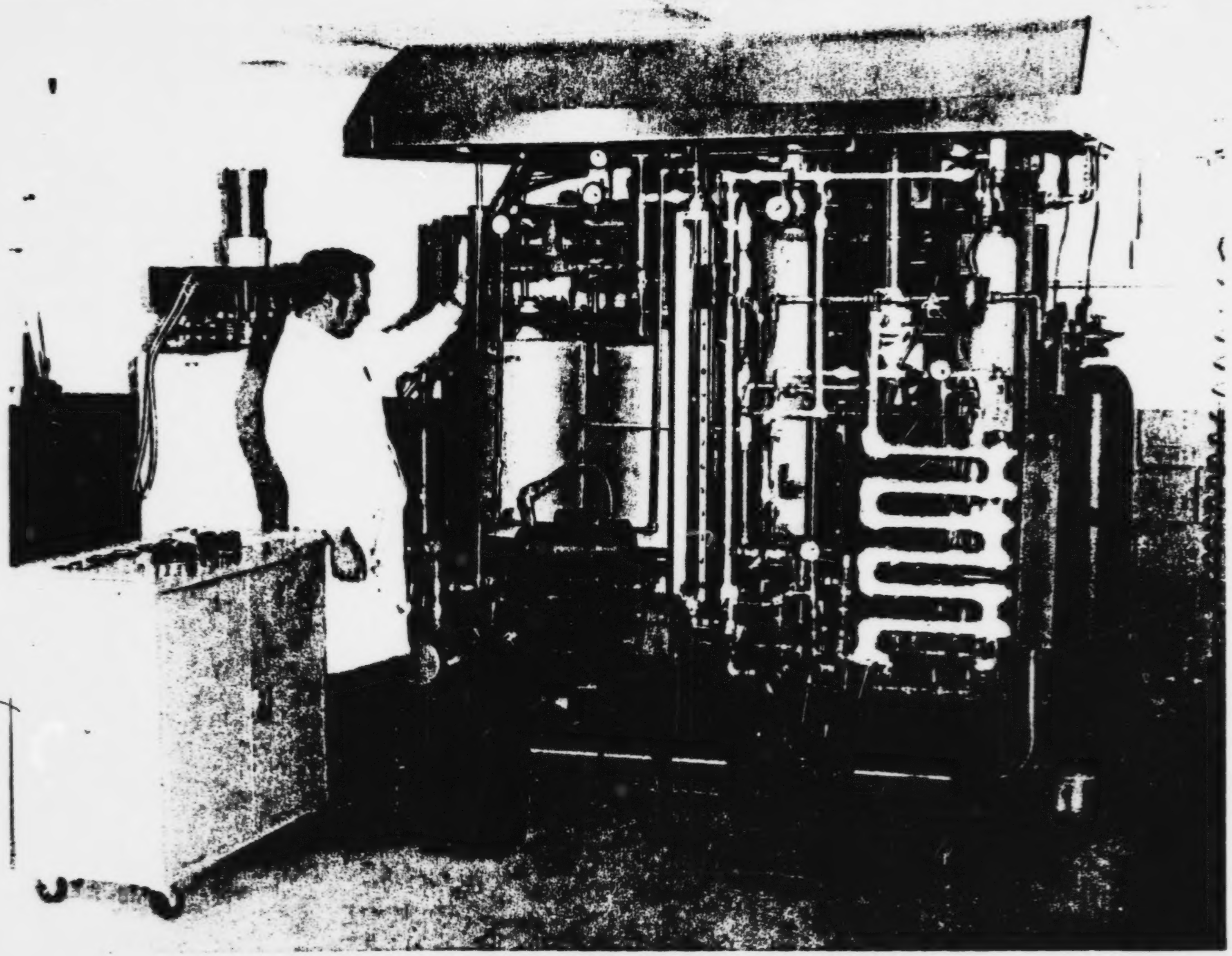


DIAGRAM 11.1 – PILOT PLANT FOR EMULSION TREATMENT

11.2 Test Procedure (cont'd)

The bottle test is carried out to select a suitable treating compound which will most effectively break the emulsion. The result of this test is also used to find out the ratio of the chemicals to emulsion which will be required.

Produced fluid is again mixed and pumped by a variable speed pump to the treating vessel through a line heater, to obtain the desired treating temperature. The chemicals are injected by a metering pump down-stream of the transfer pump, at a predetermined rate to permit mixing with the produced fluid. Heated and chemically treated produced fluid is sent to the first electrostatic treater. This vessel can be used as an electrostatic field or as a free water knock-out.

In this vessel most of the free water is separated and the top layer made up of the oil phase is sent to No.2 vessel. Oil/water interface created in vessel No.1 is continuously tested every hour.

Coalescence of the suspended water droplets in the oil phase is carried out in Vessel No. 2. Conductance type probes are used for interface control for produced water from both vessels and solonoid valves are used for the water discharge. Produced oil from No.2 vessel is sent to a blow down vessel which is periodically discharged by gravity to another storage tank. Effective parameters such as type and rate of chemicals, temperature, pressure and voltage in both electrostatic treaters, have been changed each hour in the test run in order to obtain 0.5 max BS & W in the produced oil.

11.2 Test Procedure (cont'd)

In each test, one or two of the parameters have been varied and the others have been kept constant to investigate the effect of various parameters on the final oil product quality. Quality of the produced oil was checked each hour on the basis of BS & W test results.

The test runs on both samples were carried out by determining the type and quantity of the most suitable chemicals for treatment. The treatment of the samples was then carried out at a constant flow rate of 10 Bbls/ft^2/day, for each test run. Three types of chemicals identified as 9529, 764 and 9318 were used in the test runs. Each sample was fed to the mixing vessel and transfered from the mixing vessel to the treating system by a transfer pump. Chemicals at a constant rate, (11 Qts/100 Bbls Feed) were injected by a mixing pump into the feed line down-stream from the transfer pump.

The mixture was heated and transfered to No. 1 and No. 2 vessels consecutively. No. 1 vessel has been used both as a free water knock-out vessel and as an electrostatic treater where most of the free water settled down.

Only the oil/water interface created in the No. 1 vessel has been tested during each test for BS & W and solids. Changes in quality were noted due to the change of parameters.

The oil phase from the No. 1 vessel is sent to the No. 2 vessel acting as an electrostatic treater for dehydration. The oil product from the No. 2 vessel was tested for BS & W.
Figure 12.1 gives the variation of viscosity with temperature for Sample A and B.

11.0 DESCRIPTION OF THE PILOT PLANT FACILITIES AND TEST PROCEDURES (cont'd)

11.2 Test Procedure (cont'd)

The parameters which varied during the test runs were: heater outlet temperature, pressure and electrical voltage. These changes are given below:

Heater Temperature - 129 - 138°C
Outlet Temperature - 104 - 118°C
Pressure - .34 - .40 MPa
Voltage - 6900 - 20700 volts.

The physical properties of the produced fluids are shown in Table 11.1.

TABLE 11.1

PHYSICAL PROPERTIES OF THE PRODUCED OIL

Produced Oil Properties	Samples	
	A	B
Gravity API	12.7	12.9
BS & W Vol. %	0.3	0.5
Viscosity at SSU	1427 @ 65.6°C 905 @ 73.9°C 610 @ 82.2°C	1010 @ 82.2°C 677 @ 79.4°C 428 @ 87.8°C

12.0 RESULTS, ANALYSIS AND DISCUSSION

The test run results showed that by application of thermo-physico-chemical and electrostatic fields, oil with a maximum of 0.5% by vol. BS & W can be obtained from both samples A & B.

Free water is separated in vessel No.1 by gravity technique where chemicals have been effective in demulsification of the oil/water emulsions. This causes the water to be settled. Heating on the other hand, has increased the rate of separation by reducing the time of the settling of water by creating a difference between specific gravities of oil and water. Heating also reduces the viscosity of the oil. This makes the chemicals more reactive because the compounds react faster with the fluid at higher temperatures.

Sample A was tested at a temperature of 104°C and a pressure of 0.34 MPa respectively as a voltage of 690 volts was applied to vessel No 1. This yielded an oil with high water content (1.1 - 1.5%). Solids in the oil/water interface was found to have BS & W of 0.5 and 0.1% respectively.

When the vessel No. 2 was used with an applied voltage in the range of 11500- 20700 volts and the temperature and pressure was increased to 116°C and 0.4 MPa respectively, the water content in the oil was decreased to 0.2 - 0.3% which is 1/3 of that found in previous tests.

By changing the type of chemicals and using the No. 1 vessel as free water knock-out, the water content in the oil was increased.

Another chemical blend (9318) was introduced into the feed to obtain the desired results. The test was carried out at a constant temperature and pressure of 116°C and 0.4 MPa respectively.

As a result, BS & W in oil/water interface of vessel No. 1 was reduced from 8% to 4%. The water content in the produced oil was also lowered to an average of 0.3%. The pressure of the system was increased to 0.4 MPa and by the increase of the voltage in vessel No. 1 and vessel No. 2 to 8000 and 13800 volts, the water content in the produced oil was reduced to an average of .26% (minimum 0.1%) and BS in the oil/water interface in vessel No. 1 was found to be nil. The results of these test runs are given in Table 12.1.

It is evident from the BS & W of the raw produced fluid that about 50% water in the produced fluid cannot be separated by a gravity settling treatment. It was found that in both cases, for samples A & B, the settling problem could be solved by the use of a suitable blending of chemicals.

The effect of temperature also promotes the demulsification of oil/water emulsions.

The use of electrostatic treaters in treatment of water in oil emulsions reduces the water content in the oil. A further improvement in separating water/oil emulsions has been obtained by increasing voltage of the system.

It was also observed when the power for vessel No. 1 was off, the BS in the oil increased gradually from zero to 0.8%. This shows that for removal of the water and solids from oil, the application of the electrostatic treater in vessel No. 1 is very effective.

DAYS		Day 1	DAY 2				DAY 3					DAY 4					DAY 5					DAY 6				
Test Run, No.		1	Start 1:30	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Emulsion Charge Rate, bbls/sq. ft/day		8		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Chemical Blend, No.		9529		9529	9529	9529	9529	9529	9529	9529	9529	9529	9529	9529	9529	9529	764	764	764	764	764	764	764	764	764	764
Chemical Rate - Qts/100 bbl		12		10	9	8	10	10	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Temperature °C	Out				104	110	104	110	110	104	104	118	118	118	118	118	118	118	118	118	118	121	118	116	116	116
	HT	138		138	138	132	138	135	135	132	132	132	132	129	129	132	132	132	129	129	129	138	132	127	127	127
Pressure - MPa		.34		.34	.34	.34	.34	.34	.34	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.39	.39	.40	.40	.40
Emulsion In. % BS						20											12	12	4						8	4
Emulsion In,	% H_2O	55		60	52	30	52	60	40	39	40	58	59	44	50	47	36	44	36	54	46	36	38	40	38	42
	% Solids	TR		TR	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	TR
Applied KV % (100% 23000 Volts)	No. 1					70	40	40	30	30	90	30	30	30	OFF	OFF	30	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	No. 2											70	70	50	50	90	70	70	70	70	OFF	OFF	OFF	OFF	OFF	OFF
Oil Out % BS	No. 1	00		00	00		00	00	00	00	00	00	00	00	00	00	00	00	TR	0.2	1.0		.4	.5	.7	0.5
	No. 2	00		00	00		00	00	00	00	00	00	00	00	00	00	00	00	00	00	00		.2	.2	.1	0.3
Oil Out % H_2O	No. 1				0.1	2.0	0.4	1.1	1.1	0.4	1.5	0.3	0.4	0.4	0.5	0.6	0.4	0.4	1.0	1.6	1.5	6.0	1.8	1.4	1.1	2.0
	No. 2											0.1	0.2	0.2	0.3	0.2	0.1	0.2	0.4	0.5	0.7	2.8	1.8	1.0	1.0	1.0
Oil Out % Solids	No. 1				1.0	2.0						0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	No. 2				0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.1	-
Oil/Water	BS %	0.4					0.2	TR									0.3	0.2	1.0	0.6			0.8		2.0	0.8
Interface	Water %	3.0		0.7	2.0	3.2	4.4	4.4	1.3	6.4	6.0	4.0	3.0	3.3	2.6	4.0	3.6	3.0	5.0	4.0	15	12	7.0	16	16	20.0
In Vessel No. 1	Solids	0.1		0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.3	0.2	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	TR	TR	TR

No. 1:	No. 1 Vessel
No. 2:	No. 2 Vessel
BS:	Basic Solids

TABLE 12.1

PILOT PLANT TEST DATA FOR
PRODUCED FLUID, SAMPLE A

The effect of the electrostatic field was investigated in test runs by cutting off the power supply to vessel No. 1. BS & W in oil/water interface increased gradually from 3.9 to 4.6%. This effect was more pronounced because BS & W increased from 15 - 20% when the power supply for No. 2 vessel was off. It was found that by increasing temperature to 116°C, pressure to .40 MPa and by increasing voltage to vessel No. 1 from 700 to 1500 volts, the oil/water interface BS & W in vessel No. 1 was reduced. This resulted in a reduction in BS & W in the oil product.

Results of the test runs for Sample B are given in Table 12.2.

Sample B was found to be more difficult to break than Sample A, probably due to a more stable emulsion character than Sample A. A variation of their viscosities are given in Figure 12.1.

Treatment of this emulsion was carried out at a temperature of 116°C and at a pressure of .40 MPa maximum. The voltage applied to the No.1 and No.2 vessels was kept constant at 9200 and 15000 volts respectively.

TABLE 12.2

PILOT PLANT TEST DATA FOR PRODUCED FLUID, SAMPLE B

DAYS		DAY 1				DAY 2					DAY 3				DAY 4					
Date Start - 1:00 7-24-84		2:00	3:00	4:00	5:00	12:45	1:45	2:45	3:45	4:45	1:30	2:30	3:30	4:30	12:00	1:00	2:00	3:00	4:00	5:00
Test Run, No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Emulsion Charge Rate, bbls/sq ft/day		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Chemical Blend, No.		9529	9529	9529	9529	9529	9529	9529	9529	9529	9318	9318	9318	9318	9318	9318	9318	9318	9318	9318
Chemical Rate - Qts/100 bbl		12	13	13	15	12	12	11	13	13	13	13	12	11	13	13	13	13	13	13
Temperature °C	Out	121	118	116	116	121	116	116	116	116	118	118	118	118	118	118	118	118	118	118
	HT	132	129	124	124	138	129	129	129	129	135	135	135	135	135	132	132	132	132	132
Pressure - MPa		.41	.41	.41	.41	.39	.39	.39	.39	.39	.39	.39	.39	.39	.41	.41	.41	.41	.41	.41
Emulsion In. % BS		8		16				TR		18		10	5	8	0.2	0.2	0.2			0.3
Emulsion In.	% H_2O	34	48	40	38	60	42	46	44	30	36	40	40	28	58	52	50	34	50	55
	% Solids	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR	0.1	0.1	0.1	TR	TR	TR
Applied KV% (100% 23,000 volts)	No. 1	35	40	40	50	40	40	40	40	40	40	40	40	50	35	35	35	OFF	OFF	OFF
	No. 2	70	70	50	70	70	70	70	70	70	50	50	50	60	60	60	60	60	OFF	OFF
Oil Out % BS	No. 1	0.2	0.1	0.5	0.4	00	TR	00	00	00	TR	TR	TR	–	00	00	00	00	0.2	0.5
	No. 2	0.1	0.1	0.1	0.3	00	00	00	00	00	TR	–	TR	TR	00	00	00	00	00	00
Oil out, % H_2O	No. 1	0.1	0.8	3.5	3.6	0.7	1.1	1.8	1.8	3.2	0.4	.9	1.5	1.9	0.5	0.6	0.7	1.0	1.6	2.4
	No. 2	0.2	0.3	1.1	1.2	0.2	0.3	0.6	0.8	1.0	0.2	0.2	0.4	0.6	0.1	0.3	0.4	0.6	0.7	1.3
Oil out % Solids	No. 1	TR	0.1	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.1
	No. 2	TR	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	TR	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Oil/Water Interface In Vessel No. 1	% BS	2.0	0.6	0.5	0.4	0.2	0.4	0.6	0.6	1.6	–	–	0.4	0.5	–	–	–	–	–	6.0
	Water	9.2	6.0	5.2	5.0	3.6	5.8	7.2	4.4	6.4	3.6	5.0	3.5	6.0	10	8	3.4	7.0	16	24
	Solids	TR	TR	TR	TR	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.1	TR	TR

No. 1: No. 1 Vessel
No. 2: No. 2 Vessel BS: Basic Solids

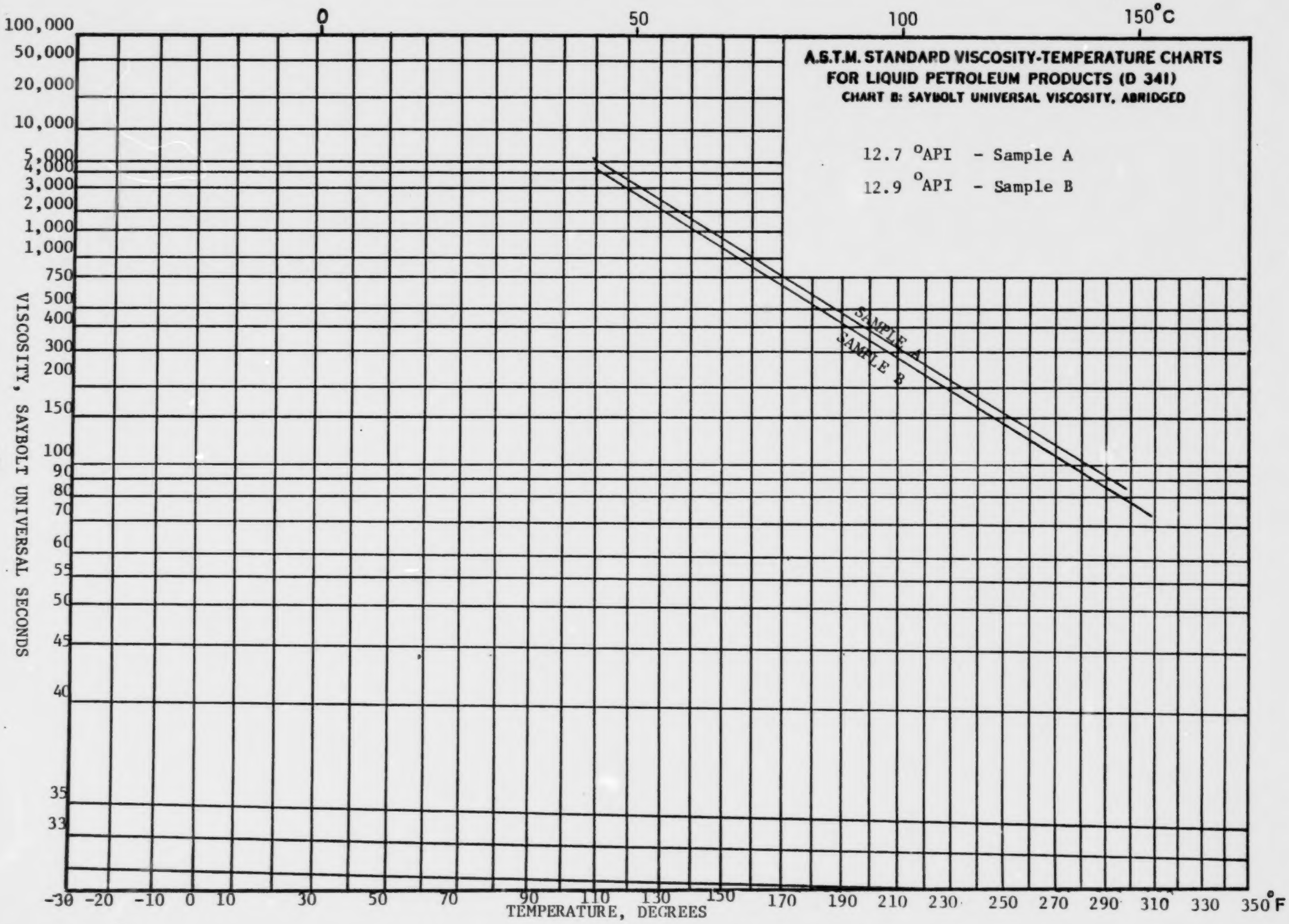


FIGURE 12.1 - VARIATION OF VISCOSITY WITH TEMPERATURE

SECTION 1V

ASSESSMENTS

13.0 TECHNICAL ASSESSMENT

The produced fluid is treated to produce oil free of water and solids.

- Gravity separating systems are the simplest and least expensive method for the treatment of the produced fluid which yield an oil with a maximum of ·5%BS & W. However, these methods are not efficient and need improvements to overcome some of the following problems:

- Loss of light hydrocarbon through vent to atmosphere.
- Untreated oil/water interface, which remains unresolved.
- Lower oil yield due to losses.
- Air and water pollution due to incomplete treatment.
- Occurrence of problems in the reservoir formation media due to the injection of untreated produced water into the disposal well.

Improvement to this type of treatment can be effected by incorporating the following in the process:

- Decreasing the viscosity of oil by the application of heat; and dilution to locate an effective difference in the specific gravities of oil and water. Diluents for oil with minimum insoluble organic compounds are preferred. This aids in thinning the film on the solid particles and is effective in separation of the oil/water emulsion. The separation is facilitated by the use of chemicals and a coalescing separation with hydrophilic and hydrophobic membranes to coalesce small oil droplets into larger droplets.

- Separation and treatment of oil/water interface to remove suspended fine solids associated with organic compounds. These particles are stabilized in oil/water interface and are not separated in the prevailing treating method. This further treatment might be carried out by the use of hydrophobic sieving or by air flotation followed by filtration.

- Removal of the impurities from the produced oil which contains 2 - 5% of water and solids in the form of water/oil emulsions. The impurities could be removed by the application of electrostatic field and/or evaporation of water. In the presence of a conductive phase, electrostatic treatment is preferred because this technique does not leave any traces of material, otherwise the water evaporation technique is used.

- De-oiling as part of the overall water clarification using state-of-the-art technology.

- Major oil companies use skimmed oil and/or condensate and refinery products as diluents. This not only reduces the viscosity of oil or bitumen, but facilitates the transportation of the final products. In these systems, effort has been made to recover the maximum oil produced. In spite of this, some organic and inorganic solids, which cannot be treated, are removed from separators. Oil/water interface with organic materials consisting of fine particles of solids may be removed by skimming and air flotation. Non-soluble materials are separated by passing the effluent through filters. Removal of precipitated solids in the separators is one of the problems presently being encountered in the industry. Accumulation of these solids reduces the separation efficiency. On removal of these organic and inorganic solids from different vessels, a small portion of the oil is lost causing pollution at the site. Efforts should be made to solve this problem.

13.0 TECHNICAL ASSESSMENT (cont'd)

State-of-the-art technologies for water treatment are more than adequate for this application and are being applied economically.

14.0 COST ESTIMATES

Six methods have been developed by SNC for the separating of oil and water from emulsions. These 6 methods represent the best of all methods available in the industry and could handle any requirements for emulsion separation.

Capital costs have been estimated for the 6 separating methods based (a) on quotations from suppliers for cost of equipment and (b) on installation costs for similar equipment according to SNC experience. These are presented in Table 14.1.

The Operational and Maintenance Cost for the above mentioned systems at 1000 B/D have been developed using information from operators in the field of emulsion separation and adapted for this study. These are presented in Table 14.2.

The Life Cycle Cost comprises the Capital Cost, the Operation and Maintenance Cost and an Insurance Cost considered for a Life Cycle period of 15 years.

The Life Cycle Cost is expressed by the following:

$$LCC = CC + (U+M+I)\frac{1}{(1+i)^n}$$

where LCC = Life Cycle Cost
CC = Capital Cost
U = Utility Cost
M = Maintenance Cost (.03 CC)
I = Insurance (.01 CC)

DESCRIPTIONS	GRAVITY SEPARATION (1000 B/D) FIG: 14.1	GRAV. & ATMOS HEATING SEPARATION (2500 B/D) FIG: 14.2	GRAV & PRESS HEAT SEPARATION (1000 B/D) FIG: 14.3	GRAV PRESS. ELECTRO HEATER SEPARATION (2500 B/D) FIG 14.4	DILUTION./GRAV/PRESS ELECT. HEATER SEPARATOR (1500 B/D) FIG: 14.5	DILUTION/GRAV/PRESS HEATING AND/OR HIGH TEMP EVAP. (1500 B/D) FIG: 14.6
QUOTED EQUIP. COSTS	146250	301250	311250	332500	351250	613750
CHEMICAL INF. FACILITIES	6000	6000	6000	6000	6000	6000
INSTALLATION	52000	190000	100000	100000	105000	135000
SUB-TOTAL	198300	393000	411000	433000	457000	749000
PIPING ELECTRICAL CONTROLS	100000	240000	267000	281000	320000	449000
CIVIL/STRUCT.	45000	95000	102000	107000	117000	240000
TOTAL DIRECT COSTS	343000	728000	780000	821000	894000	1438000
INDIRECTS - FLD. IND. - ENGINEER - CONSTR. MAN.	87000	182000	195000	205000	223000	360000
SUB-TOTAL	430000	910000	975000	1026000	1117000	1798000
CONTINGENCY	65000	140000	145000	154000	163000	272000
TOTAL CAPITAL COST	495000	1050000	1120000	1180000	1280000	2070000

TABLE 14.1

COST ESTIMATE FOR OIL/WATER EMULSION SEPARATION EQUIPMENT

SEPARATION METHODS / COST DESCRIPTION	GRAVITY SEPARATION FIG: 14.1	GRAV. & ATMOS. HEATING SEPARATION FIG: 14.2	GRAV. & PRESS. HEAT SEPARATION FIG: 14.3	GRAV. PRESS. ELECTRO. HEATER SEPARATION FIG: 14.4	DILUTION/GRAV/PRESS. ELECT. HEATER SEP. FIG: 14.5	DILUTION/GRAV/PRESS HEATING AND/OR HIGH TEMP. EVAP. FIG: 14.6
CAPITAL COSTS	$495,000	$605,978	$1,120,000	$681,005	$1,003,666	$1,623,117
OPERATIONAL COSTS (15 years)	$1,661,688	$2,239,567	$2,606,688	$4,704,300	$3,705,508	$2,758,830
LIFE CYCLE COSTS (15 years)	$2,156,688	$2,845,545	$3,726,688	$5,385,300	$4,709,174	$4,381,947

TABLE 14.2

COST COMPARISONS FOR 6 OIL/WATER EMULSION SEPARATING METHODS BASED ON
A CAPACITY OF 1000 B/D

14.0 COST ESTIMATES (cont'd)

i = Discounting factor 10%

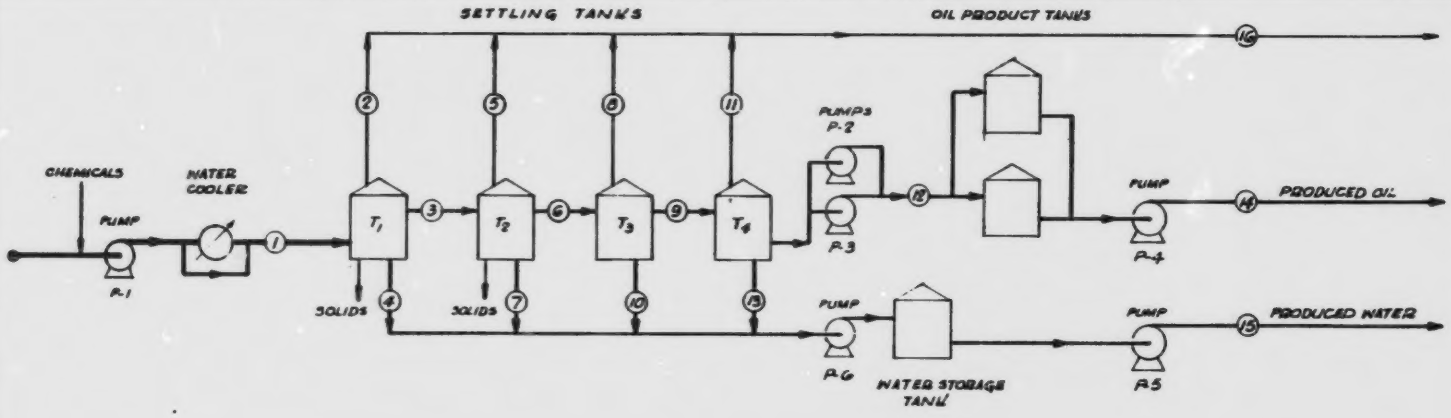
n = Life cycle period (15 years)

The Life Cycle Costs for the 6 separating methods at 1000 B/D capacity, are presented in Table 14.2.

Flow sheets of the processes involved for each of the 6 methods are presented in sketches in Figures 14.1 to Figure 14.6.

The Costs are given in constant dollars (1984) and are accurate to ± 25%.

The Capital Cost estimates are converted to the same basis of 1000 B/D for comparisons in Table 14.2.



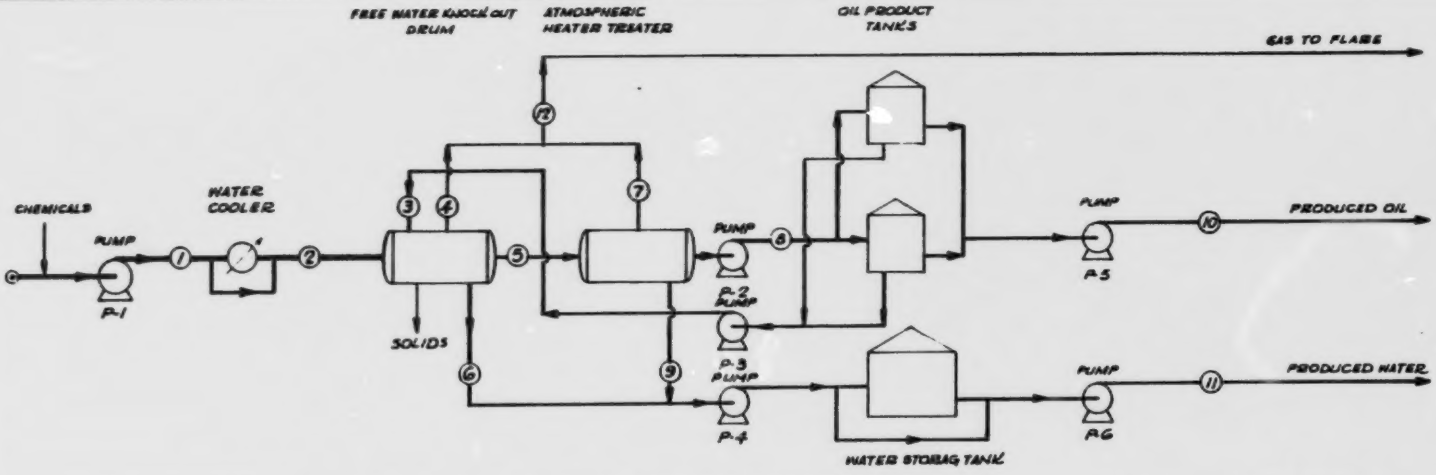
N.B. VENDOR TO SUPPLY ALL THE RELEVANT TECHNICAL DATA ON EQUIPMENT.

STREAM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
IDENTIFICATION	COOLED [illegible]	GAS EX T1	OIL PHASE EX T1	WATER EX T1	GAS EX T2	OIL PHASE EX T2	WATER EX T2	GAS EX T3	OIL PHASE EX T3	WATER EX T3	GAS EX T4	OIL EX T4	WATER EX T4	PRODUCED OIL	PRODUC. WATER	GAS TO FLARE	
TEMPERATURE °C	115	95	95	95	90	90	90	88	88	88	85	85	85	78	75	-	
PRESSURE PSI	10	ATMOSPHERIC →															
OIL API	18																
WATER TO OIL RATIO	1																
SOLID CONTENT BY VOLUME	8%																
WATER DROPLET SIZE	>60																
VISCOSITY OF THE OIL @25°C	9000CP																
BS & W. OF THE OIL MAX. %	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5			
T/P BARREL PER DAY	1000																
SETTLING TIME FOR WATER	20-50 HRS →																

CLIENT OIL/WATER EMULSION SEPARATION	M. PYLAT		84.02.10
SNC GRAVITY SEPARATION	7122 0000	49DO	3K-A1 PA

FIGURE 14.1

GRAVITY SEPARATION SYSTEM



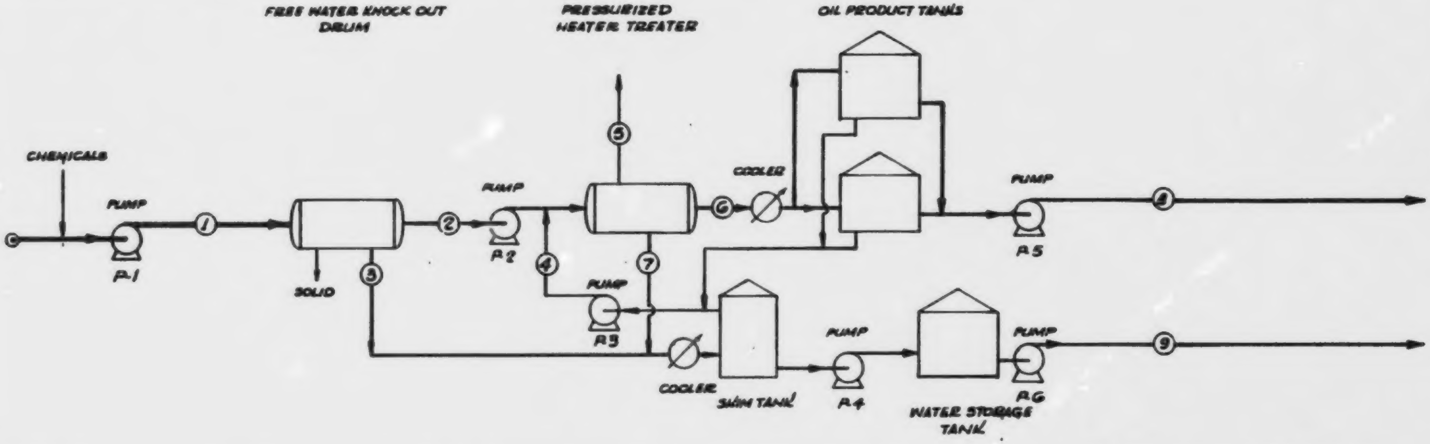
STREAM	1	2	3	4	5	6	7	8	9	10	11	12
IDENTIFICATION	PRODUC. FLUID	COOLED [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	OIL OUT	PRODUC. WATER	GAS OUT
TEMPERATURE °C	120	90	80	88	88	88	65	65	65	80	80	-
PRESSURE PSI	60	60	60	50	50	50	35	35	35	ATMOS	ATMOS	
RETENTION TIME FOR:	-	-	-	-	20 HRS	48 HRS	-					
API OF THE OIL	13											
VISCOSITY AT 21°C	5000 CP											
WATER CONTENT BY VOL.	30%											
BS&W MAX %	-									0.5		
T/P BBLS/DAY	2500											

N.B. VENDOR TO SUPPLY ALL THE RELEVANT TECHNICAL DATA ON EQUIPMENT.

OIL/WATER EMULSION SEPARATION	M. PYLAT		94.02.10.
SNC GRAVITY AND ATMOSPHERIC HEATING SEPARATION SYSTEM	7122 0000	49D0	W-A PA

FIGURE 14.2

GRAVITY AND ATMOSPHERIC HEATING SEPARATION SYSTEM



N.B. VENDOR TO SUPPLY ALL THE RELEVANT TECHNICAL DATA ON EQUIPMENT.

STREAM	1	2	3	4	5	6	7	8	9
IDENTIFICATION	[illegible] FLUID	OIL OUT FWKO	[illegible]	[illegible]	GAS OUT PHT	OIL OUT PHT	WATER OUT PHT	OIL PRODUCT	[illegible] FLUID
TEMPERATURE °C	25	25	25	70	120	120	120	80	80
PRESSURE PSI	10	ATMOS	ATMOS	70	70	70	70	ATMOS	ATMOS
API OF THE OIL	12								
RETENSION TIME						68 HRS	8 HRS		
VISCOCITY OF THE OIL @25°C	5000 CP								
WATER CONTENT BY VOL.	50%								
SOLID CONTENT	3%								
T/P BBLS/DAY	1000								

OIL / WATER EMULSION SEPARATION

GRAVITY AND PRESSURIZED HEATING SEPARATION SYSTEM

M.PYLAT

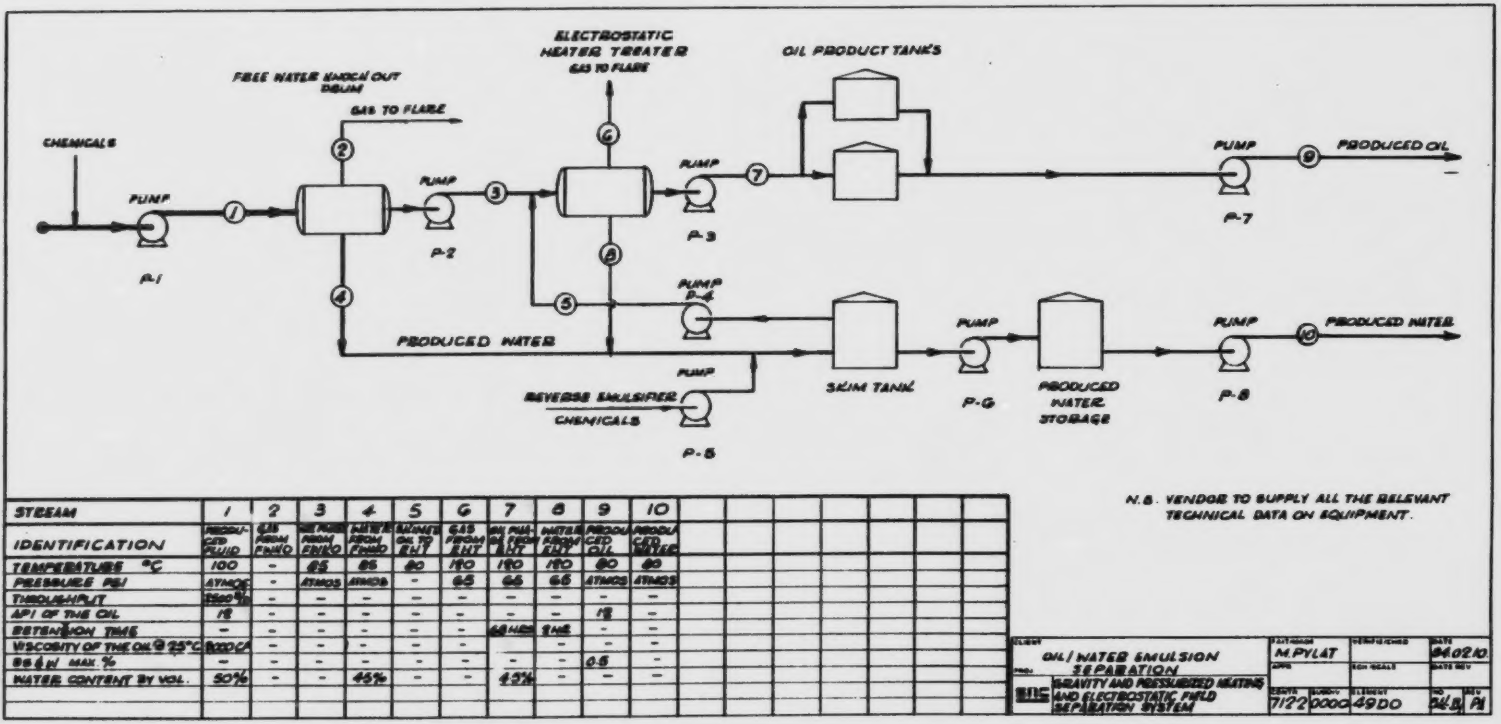
94.02.10.

-

7122 2000 49DO

FIGURE 14.3

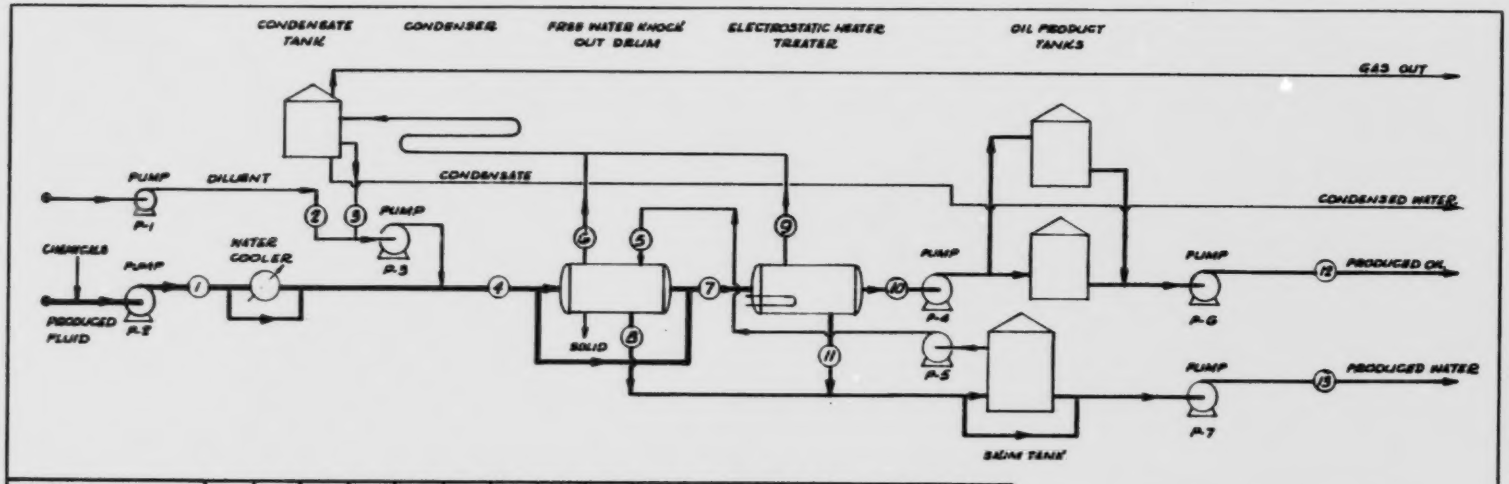
GRAVITY AND PRESSURIZED HEATING SEPARATION SYSTEM



STREAM	1	2	3	4	5	6	7	8	9	10
IDENTIFICATION	PRODUCED FLUID	GAS FROM FWKO	[illegible] FROM FWKO	WATER FROM FWKO	[illegible] OIL TO EHT	GAS FROM EHT	[illegible] FROM EHT	WATER FROM EHT	PRODUCED OIL	PRODUCED WATER
TEMPERATURE °C	100	-	85	85	80	120	120	120	80	80
PRESSURE PSI	ATMOS	-	ATMOS	ATMOS	-	65	65	65	ATMOS	ATMOS
THROUGHPUT	2500 [illegible]	-	-	-	-	-	-	-	-	-
API OF THE OIL	18	-	-	-	-	-	-	-	18	-
RETENTION TIME	-	-	-	-	-	-	48 HRS	2 HR	-	-
VISCOSITY OF THE OIL @ 25°C	8000 CP	-	-	-	-	-		-	-	-
BS&W MAX. %	-	-	-	-	-	-	-	-	0.5	-
WATER CONTENT BY VOL.	50%	-	-	45%	-	-	4.5%	-	-	-

FIGURE 14.4

GRAVITY, PRESSURIZED HEATING AND ELECTROSTATIC FIELD SEPARATION SYSTEM



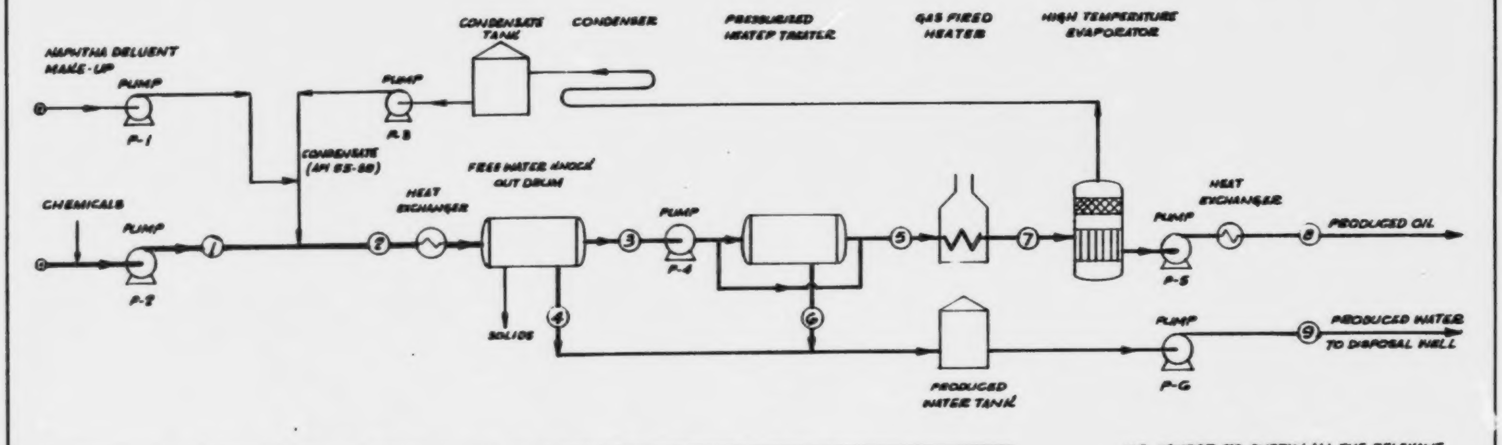
STREAM	1	2	3	4	5	6	7	8	9	10	11	12	13				
IDENTIFICATION	PRODUCED FLUID	DILUENT	CONDEN-SATE	DILUTED PRODUC FLUID	SKIMMED OIL	GAS FROM FWKO	OIL EMUL-SION FROM FWKO	WATER FROM FWKO	GAS FROM EHT	OIL FROM EHT	WATER FROM EHT	DILUTED PRODUC OIL	PRODUC WATER				
TEMPERATURE °C	150	30	30	125	70	125	125	120	120	120	120	80	80				
PRESSURE PSI	100	75	75	75	75	75	75	50	50	50	50	ATMOS	ATMOS				
API OF THE OIL	8	-	55	17		-											
VISCOSITY OF THE OIL @ 25°C	10^6 CP	-		15,000 CP								10,000 CP					
WATER CONTENT BY VOL.	50%	-					46%				4.7%						
SOLID CONTENT	2.0%	-															
CHEMICAL ADDED																	
DETENSION TIME FOR:	-	-								68 HRS	2 HRS						
T/P bbls/D	1500																
B.S.& W. MAX.%												0.5					

N.B. VENDOR TO SUPPLY ALL THE RELEVANT TECHNICAL DATA ON EQUIPMENT.

OIL/WATER EMULSION SEPARATION
SNC
DILUTION GRAVITY & PRESSURIZED HEATING AND ELECTROSTATIC FIELD SEPARATION SYSTEM
M.PYLAT
84.08.13.
-
7122 0000 49DO SK-C PA

FIGURE 14.5

DILUTION GRAVITY & PRESSURIZED HEATING AND ELECTROSTATIC FIELD SYSTEM



N.B VENDOR TO SUPPLY ALL THE RELEVANT TECHNICAL DATA ON EQUIPMENT.

HEAT EXCHANGER AS AN ALTERNATIVE TO GAS FIRED HEATER.

STREAM	1	2	3	4	5	6	7	8	9
IDENTIFICATION	PRODUCED FLUID	DILUTED PRODUC. FLUID	OIL PHASE FROM FWKO	WATER FROM FWKO	OIL PHASE FROM HEAT TREATER	WATER FROM H. TREATER	HEATED OIL PHASE	DEWATERED OIL	PRODUCED WATER
TEMPERATURE °C	26	30	90	90	95	95	165	80	80
PRESSURE PSI	-	-	50	50	35	35	-	ATMOS	ATMOS
API OF THE OIL	8	15	-	-	-	-	-		-
VISCOSITY OF OIL @ 25°C	10^6 CP								
WATER CONTENT BY VOL.	50%			48%		3%	-	NIL	-
RETENTION TIME					30 MIN	48 MIN	-	-	-
T/P BBLS/DAY	1500								

CLIENT	DRAWN BY	VERIFIED	DATE
OIL/WATER EMULSION SEPARATION	M. PYLAT		84.08.13.
PROJ.	APPR.	SCALE	DATE REV
		-	
SNC DILUTION, GRAVITY / PRESSURIZED HEATING AND/OR HIGH TEMPERATURE EVAPORATION	7122 · 2000	49DO	SK-D1 · P1

FIGURE 14.6

DILUTION, GRAVITY & PRESSURIZED HEATING AND/OR HIGH TEMPERATURE EVAPORATION

15.0 COMPARATIVE ECONOMIC ANALYSIS

The three separation processes given in Figures 14.1, 14.2 and 14.3 are characterized by the use of gravity. Of these 3 methods, the process in Figure 14.1 has very limited application and requires a large space for installation. The processes given in Figures 14.2 and 14.3 would be more often used than that given in Figure 14.1. The process given in Figure 14.3 is the most versatile of these 3 gravity methods but carries the highest capital cost of these methods. For these methods the capital costs vary from $495,000 for the process in Figure 14.1 to $1,120,000 for the process in Figure 14.3. The Operational costs for these 3 methods over a 15 year life cycle period vary from $1,661,688 for the process in Figure 14.1 to $2,606,688 for the process in Figure 14.3.

The corresponding Life Cycle costs vary from $2,156,688 for the process in Figure 14.1 to $3,726,688 for the process in Figure 14.3.

The processes given in Figures 14.4, 14.5, and 14.6 are applicable to stable or difficult emulsion separations. The Process given in Figure 14.6 is the most effective and suitable for the most difficult separations. This process is characterized by a dilution recycling step and results in the lowest operating cost of the three processes applicable to stable emulsions.

The capital costs of these three processes vary from $681,005 for the process in Figure 14.4 to $1,623,117 for the process in Figure 14.6.

The operating cost over a life cycle period of 15 years for the process in Figure 14.6 is $2,758,830 whereas the corresponding Life Cycle Costs for the processes in Figures 14.4 and 14.5 are $4,704,300 and $3,705,508.

The Life Cycle Cost over the 15 year period for the process in Figure 14.6 is $4,381,947 which is less than the corresponding Life Cycle Cost for the processes in Figures 14.4 and 14.5. The Life Cycle Cost for these two processes in Figure 14.4 and 14.5 are $5,385,000 and $4,709,174 respectively.

It is seen that of the 3 methods applicable to difficult or stable emulsions, the most suitable and effective separation method, even though the Capital Cost is greatest of the 3 processes, the Operational Costs and the Life Cycle Costs are the lowest for this process in Figure 14.6.

This process (Figure 14.6) originated by SNC is the most efficient and effective of all the processes.

It is recommended that a pilot study be undertaken to establish and optimize the operational parameters.

16.0 IDENTIFICATION OF PROMISING COMMERCIAL METHODS

The treating system for separation of oil and water from emulsion generally uses a combination of techniques.

The following treating systems have been adjudged to be promising for various types of emulsions.

- Chemicals, gravity separation and heater treater for medium °API heavy oil or bitumen emulsions recovered in steam thermal methods.
- Chemicals treatment, gravity separation and electrostatic treater for medium °API heavy oil or bitumen recovered in in-situ combustion method.
- Chemicals treatment, free water knock-out electrostatic treater for low °API heavy oil or bitumen emulsions recovered in steam thermal methods.
- Chemicals, dilution and electrostatic treater or evaporator for low °API heavy oil or bitumen emulsion recovered in combustion methods.

These promising methods are shown in Table 16.1.

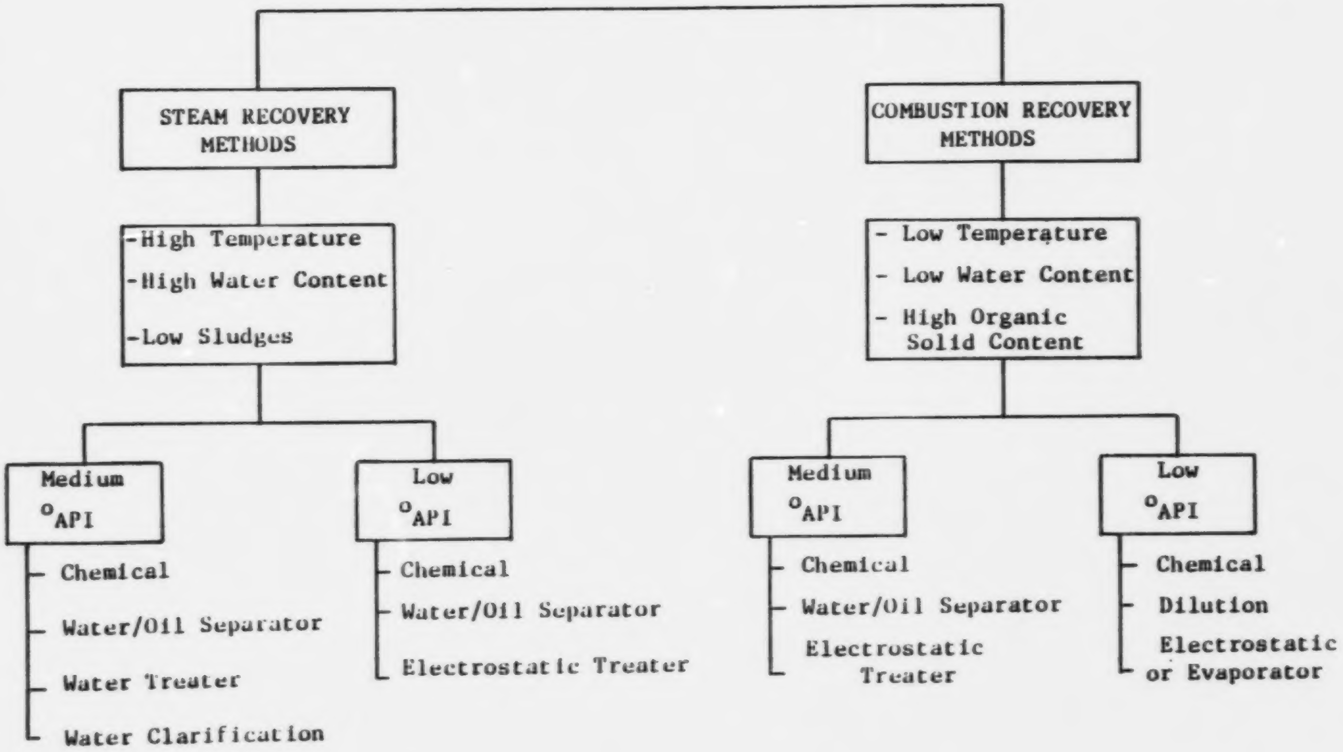


TABLE 16.1 - PROMISING TREATING METHODS

SECTION V

EMERGING METHODS

17.0 REVIEW OF EMERGING METHODS

17.1 Discussion of Ongoing Efforts

The breaking of bitumen-water emulsions as they arise by in-situ recovery methods is a very important, yet also a very difficult and complex problem. Consequently, a variety of approaches either to solve the key problem or various subsidiary problems have been also pursued in recent years.

A typical example for work on such a subsidiary problem is found in (34) which describes the recovery of residual bitumen from oil sand sludges. In this investigation dilution was found to be the most significant variable. It was established that close to 100% recovery of the residual bitumen could be achieved by flotation, after diluting one volume of sludge with two volumes of water. This finding is interesting and surprising, in view of the usual extreme stability of the original bitumen-water emulsion. Presumably, physical and chemical changes may occur during the storage period. The procedure seems to work very well for what it was designed, i.e. to remove residual bitumen from the tailings.

Another attractive specialty technique is spherical agglomeration, (33) . The process consists simply of adding coal fines to an oil-water emulsion and results in the breaking of the emulsion, leading to an aqueous phase and a coal-oil mixture. Oil removal has been shown to be very efficient. At the same time there will be a cleaning effect on the coal, due to the removal of water soluble inorganic materials in the aqueous phase. The process may well be possible even with clay stabilized emulsions because the clay is less hydrophobic than coal so that the latter will, in water, have a higher affinity for the oil phase than the clay.

17.1 Discussion of Ongoing Effects (cont'd)

While this may be an attractive proposition for certain situations, it should be realized that treatment of the initial tailings, i.e. removal of clay in low concentrations from water, may be the more pressing problem, which would call for electrophoresis rather than electroendosmosis. Here too, cost may be prohibitive.

In any case, it would seem that the treatment of tailings must be considered from the point of view of the state of the clay, particularly, the surface properties of the clay. A clay that stabilizes the bitumen-water emulsion will probably have to be removed from the bitumen-water interface by means of surfactants. These surfactants no doubt will enhance the clay dispersion in water. Any treatment of the tailings should recognize and possibly utilize this type of surfactant film on the surface of the clay particles.

The largest part of the ongoing effort in the area focuses on the breaking of emulsions by the action of chemical components, i.e. surfactants. There is a very large body of information accumulated in the study and processing of aqueous emulsions of conventional crudes, which are of the water in oil type. The stability of such and any other emulsion arises from organized monolayers at the oil-water interface. These monolayers typically consist of straight chain compounds or compounds with straight chain segments, with no side chains, that allow for a close approach and close packing of these straight chains, thereby maximizing lateral van de Walls attraction.

17.0 REVIEW OF EMERGING METHODS (cont'd)

17.1 Discussion of Ongoing Effects (cont'd)

It seems that separation of the coal from the oil phase has not beem attempted, presumably because one would consider the whole process only if the coal-oil mixture were destined for combustion purposes. However, if one were to attempt breaking a clay stabilized bitumen-water emulsion without the use of any surfactants, spherical agglomeration with coal might provide one of a very few avenues.

The use of electric fields has been considered in various instances for the processing of water-oil emulsions. Specifically electrophoretic mechanisms have been considered for the breaking of water in oil emulsions, as they occur in conventional crude oil recovery (27). Typically, such approaches can be used to coalesce the dispersed phase if it is the more polar one, i.e. water in oil emulsions. Bitumen-water emulsions, with water being the continuous phase, would probably present insurmountable problems due to electrical losses and hence lead to unacceptable costs.

Another electrostatic technique, electroendosmosis, is presently being tested (25). While in electrophoresis an electric field is used to move electrically charged droplets or solid particles, in electroendosmosis, one keeps an electrically charged solid or an ensemble of particles stationary, and allows the liquid to move. Thus electroendosmosis may be used to remove water from a sludge for example.

17.1 Discussion of Ongoing Effects (cont'd)

Demulsification is normally attempted with mixtures of different surfactants, different chain lengths and differnet molecular arrangements, e.g. side chains, to prevent film formation. Some groups must have the ability to penetrate and interrupt the stabilizing film.

Unlike conventional crudes, bitumen-water emulsions are of the oil in water type and therefore require treatment with different types of demulsifiers. In addition, they are frequently stabilized by clay particles at the water-bitumen interface which provide very effective steric shielding against coalescence. The relevant references recognize clearly the necessity of removing, first of all, the clay particles. It appears that this is the slowest step. The subsequent coalescence occurs rapidly (19). There seems to be a consensus that the only possible type of demulsifier has to be of the macromolecular variety (19 & 25). Within that group, a variety of chemical compositions and molecular weights are recommended. The most prominent group of surfactants proposed are various ethylene oxide adducts. While the mechanisms of breaking these bitumen in water emulsions by polymeric surfactants are not obvious, it appears that the removal of the clay particles from the interface is due to the increase of hydrophilic nature of the clay particles caused by absorption of the polymeric surfactants. Two points are noteworthy here: Firstly, rendering the clay particles more hydrophilic is probably only possible through the action of macromolecular and not low molecular weight materials. Secondly, the absorption of macromolecular surfactants onto the clay particles will be non-specific.

This means that there will be an almost infinite variety of compounds which will remove the clay particles from the bitumen-water interface. A corollary of the latter statement is that it might be very difficult to protect any such process through patent rights.

Besides the dilution, agglomeration, electrostatic field and chemicals, effort has been focused on development of systems which operate under physical and mechanical means, to avoid high cost where there is less contamination (such as chemicals in the system) and low °API loss, (due to high treating temperature).

Breaking of emulsions with the use of filters is a very attractive concept. This strategy may have significant advantages over its alternatives: Electrolytic and electrostatic separation processes may well prove to be too expensive to operate due to the amount of energy required. Chemicals, i.e. surfactants, may also prove to be expensive. Further concerns are possible changes of the oil phase due to the addition of surfactants and, probably more important, environmental problems due to the presence of polymeric surfactants in the aqueous phase and hence in the tailings. It has been shown that certain membrane filters, having both hydrophilic and hydrophobic domains, are capable of breaking water in oil emulsions, resulting in essentially complete phase separation (31). There is no reason to believe that such strategies would not work also for oil in water emulsions. It is possible to prevent either phase from passing through such a filter. Unfortunately, so far, the filters get clogged, stopping the separation. However, this idea of preventing one phase from passing through a filter should not be abandoned altogether. Perhaps some cross flow scheme (with slow cross flow on the upstream side) might be designed such that the phase stopped by the filter might be removed.

By using the same concept, the application of two membranes with different wetting properties, has been tested experimentally. (44). Porous membranes with hydrophobic and hydrophilic behaviour of 1.2 micron pore size have been used in this experiment, which seems to have a potential for separation of oil and water from non-stable emulsions.

Another example is a modified heater treater, by using a mechanical coalescer in the treater. Several plates of different materials are used to measure fluid contact surface area. This type of coalsecer is used experimentally in treaters and have proven to be efficient and provides better separation than the conventional heater treaters (45).

In another development, a membrane is used in ultrafiltration, (UF), which consists of multiple layers of non-cellulosic polymers, cast on porous backing meterial, controlling the pore size. (.002-.02 microns). It is operated under a pressure of 0.07 - 1.03 MPa. Suspended solids and macromolecules are retained by the membrane. These membranes are more suitable in oil/water emulsion or tailing treatment. (46).

An example of the application of a membrane is given in an ultrafiltration development of hollow fiber membranes in which a large amount of surface area is placed in a limited space. Molecules smaller than the membrane's pores pass through the walls of the membrane and larger molecules are retained. Rigid, self-supporting membrane components can withstand high pressure. (47).

17.1 Discussion of Ongoing Effects (cont'd)

Among 14 physical-chemical processes singularly or in combination which are evaluated in the separation of organic carbon compounds in effluents, the highest removals are obtained with the polyamide hollow-fiber membranes as compared to the cellulose accetate membranes. (48).

Absorbent sponge materials application for separation of oily materials from a fluid, is also a technique which has been experimented with and is used in the oil fields now. This technique is based on the organic absorbent property of the material, such as pretreated waste wood fibers. This type of material has a future application in collecting oil from emulsions and also from the surface of ponds and polluted areas.

17.2 Academic Activities

Due to the complexities of the breaking of bitumen-water emulsions, there seems to be no major effort, in academic institutions, focussing on the totality of the problem. Instead, as is typical for academic research, certain aspects of the problem are isolated and studied, in the hope of contributing, by accumulation of insight into partial aspects, to the long range solution of the problem. Alternatively, more general research topics are being pursued which may, however, have implications for the problem of breaking bitumen-water emulsions.

17.2 Academic Activities

A typical example of such work is described in a paper, (49), relevant to a possible strategy of breaking bitumen-water emulsions. The aim of the author is the elucidation of the mechanisms of coalescence of oil droplets when an oil-water emulsion flows through a filter consisting of a granular material.

A second example is the effect of HLB on demulsification of a mixture of heavy oil, water and clay, explained in a paper. (50). This paper deals with the question of finding guidelines to identify surfactants which are likely to demulsify mixtures of heavy oil, water and clay. HLB, (Hydrophilic-Liophilic Balance) provides such a guideline. The authors have found, inter alia, that the most useful surfactants for clay removal had HLB values above 20. The authors have also reported that surfactant parameters such as surface tension or interfacial tension are unrelated to demulsifying ability.

In another paper, (51), by contrast, it is found that rapid coalescence rates are associated with low interfacial tension systems, indicating a strong influence of interfacial tension on coalescence rate behaviour.

Another example is the development of a technique for measuring liquid interfacial tensions from the shape of axisymmetric drops (52). One of the advances in this method is its excellent performance at low and ultra-low interfacial tensions, even at elevated temperatures and pressures.

17.2 Academic Activities (cont'd)

The main conclusion from the consideration of these research efforts in academic institutions is that they have, not surprisingly, yielded presumably useful and interesting results, but they have advanced no approaches for the breaking of bitumen-water emulsions in addition to those discussed in the main body of this report. To attempt a more complete account of such efforts would not be productive at this time. Such efforts may prove very helpful once decisions regarding the approach or approaches to be pursued have been made. At that time, a search focussed on the actual problem areas of that approach might be conducted.

18.0 CLASSIFICATION OF EMERGING METHODS

A number of investigations have been carried out in recent years to find out a suitable method in which heavy oil or bitumen stable emulsions can be destabilized. Different classes of emerging methods are used based on the same concept. These emerging methods have been studied and are classified as follows:

Chemicals

Chemicals have been used in different forms, sometimes in combination with diluents to destabilize a specific type of bitumen emulsion.

Demulsifers

Many types of chemicals come under this title and those which have been used for the recovery of bitumen from oil/water emulsion are water soluble demulsifier chemicals. This class of chemical includes polyethylene oxide and propylene oxide. Non-ionic polyethylene oxide polymers have also been used with diluents, together with an alkaline earth metal halide ($CaCl_2$). Polyethylene polymeric resin with high range molecular weight has been used for separation of bitumen from the produced fluid, in an in-situ tar sand plant. Polyethylene oxide resin of an alkali metal hydroxide has been used to remove clay particles, resulting in destabilizing of emulsions.

Different chemicals have also been used as additives or demulsifiers to break diluted emulsions. Fire flood emulsions which seem to be the most stable emulsions have been the main target for demulsification.

Demulsifiers (cont'd)

The following classes of chemicals have been found to be effective in destabilizing of a number of emulsions.

- Short chain water insoluble aliphaltic alcohols are the most effective demulsifiers, including hexadecanol and octadecanol.
- Short chain alkylphenol such as monylphenol.
- Low carbon chain alkyl ketone and diketones especially the water insoluble ones, are effective demulsifiers.
- Low chain fatty acids such as oleic acid has been in the same range of effectiveness.

Absorbents

Several types of materials have been used in absorption of oily particles from emulsions. The application of these materials is based on the physical-chemical properties and is used in the form of powder and plates.

Coal powder which has a hydrophobic property, has the tendency to absorb more oil than water. A class of coal with more fatty acid and alcohol compounds is expected to be more effective in the absorption of oil particles from an emulsion. The type of coal and particle size of the powder are the main factors affecting the separation.

18.0 CLASSIFICATION OF EMERGING METHODS (cont'd)

Absorbents (cont'd)

Oleophilic bodies have been used for agglomeration and sieving. These materials absorb the oil, causing the creation of larger sized droplets and then they are collected in the sieve.

Membranes

Various types of separators with two membranes having different wetting properties have been used. A system in this class consists of two porous membranes having different wetting behaviours.

Oil rises and contacts the upper, hydrophobic membrane and water will be in contact with the lower membrane. Using this method, the larger droplets will be produced which are then separated.

Mechanical Coalescing Media

This class of emerging methods consists of a matrix of plates that increases fluid contact surface area. Small water droplets impinge on the surface of the plates, coalesce and flow down into the water phase. Different types of materials have been used and are now being tested. Their performance is satisfactory for the application of suitable plates in specific areas.

Dilution and Caustic and Lime Addition

Dilution and addition of caustic and lime have been examined for separation of bitumen from residual bitumen obtained by flotation from oil sands tailings sludges.

Dilution and Caustic and Lime Addition (cont'd)

Dilution has been found to be the most significant variable and it was established that close to 100% recovery of the substantial quality of residual bitumen could be achieved by flotation, after diluting 1 volume of sludge with 2 volumes of water.

A bitumen and deasphalting process has been developed by Bitech Energy Resources Ltd., Toronto, for separation of bitumen from oil sands and it is claimed that in this process, difficult fire floods emulsions are broken with steam and water is recovered for possible reuse. Details of this system have not been released yet.

Ultrafiltration

A method has been developed to break W/O and O/W emulsions with the emulsified droplets having a diameter at least .02 micron. Emulsion is passed through a micro-pore membrane with pores having a size of at least .03 micron, with hydrophilic property and hydrophobic zones. The system can operate at ambient temperature and under pressure. The membrane may be made of natural, synthetic or artificial fibres. Polytetrafluoroethylene, (PTEE) and polysulphone (pore size .003 micron), have been used experimentally.

A pleated, thin channel, cross-flow module is used for filtration of particulates and emulsions. In this method of hollow fiber design with hydrodynamics of plate and frame units containing turbulence promoting elements have been used. This consists of a circular array of parallel pleated thin channels, each of whose inner wall is a membrane supported by a porous backing resting on a central product drain tube.

18.0 CLASSIFICATION OF EMERGING METHODS (cont'd)

Ultrafiltration (cont'd)

The outer flexible wall is separated from the membrane by a turbulence promoting space and serves to create the flow channel, without fulfilling a direct filtrative purpose.

Ultrafiltration for separation of materials, is also carried out on the basis of molecular size, without any change on the nature of the phases. This method involves a pressure-driven filtration membrane which separates solutes from solvents according to molecular size, shape and chemical bonding, by hydraulic pressure, and in which larger molecules remain behind. This technique has been used for oil-water emulsions. Depending on the nature of the feed, when a pressure drop is observed, the untrafiltration unit is cleaned with detergent prior to further operation.

Hollow Fiber Membrane Method

Another emerging method is to apply a large amount of membrane surface in a limited space. Hollow fiber membranes are examples in this area.

Using this method a series of cartridges resembling shell-and-tube heat exchangers are used. The highest removals of oil have been obtained with the polyamide hollow-fiber membranes as compared to the cellulose accetate membranes.

Electrostatic Field

A second electrode is fluid-coupled to the driven electrode, which is directly connected to either an AC or DC source of potential.

Electrostatic Field (cont'd)

The driven electrode is provided with the usual grounding to establish the electrostatic field of a coalescing system. The electrode fluid coupled to the driven electrode is positioned in such a way that it establishes two zones in the electrostatic field. A fluid mixture is passed through the two zones of the electrostatic field, in sequence. The intensity of the field in the first zone decreases as the dispersed polar fluid of the mixture increases, in relation to the less polar fluids of the mixture. At the same time, the field in the second zone increases in intensity. The field gradient shifts between the two zones, in accordance with the quality of the polar fluid in the mixture passed through the zones in the field, in sequence. This process is patented by a number of manufacturers, e.g. C.E. NATCO.

Magnetic Separation

Single wire, high gradient magnetic separation (HGMS) is qualitatively experimented for separation of oil and water from emulsions. It is shown that magnetic separation may be used when:

- The continuous phase is a paramagnetic liquid and the discrete phase is a diamagnetic liquid.

- The continuous phase is a diamagnetic liquid and the discrete phase is a paramagnetic liquid.

Control of the paramagnetic aqueous fluid is obtained by adding a paramagnetic salt to water.

This does not appear to follow models for solid particles.
To separate a heavy crude oil emulsion into gas, brine and oil, an apparatus based on the above principle is developed and patented. The emulsion passes through three zones, heating, separation and electrical resulting in coalescence of water droplets.

Electrostatic Field (cont'd)

Oil free of brine in the top layers flows from the third zone over a wall into a reservoir, with the wall serving the dual function of maintaining the liquid level in the third zone at an elevation where the electrodes that supply the high potential electrical field are at all times immersed in the oil. This also prevents brine-free oil in the reservoir from mixing with the oil that is being treated in the third zone. Gas is accumulated in the upper portion of the zones and is withdrawn. Accumulated brine is also removed from the bottom and oil is discharged from the top. This process is patented and the trend today is to commercialize some types of these equipments.

19.0 IDENTIFICATION OF PROMISING METHODS

Extensive experiments have been carried out to break stable emulsions. For destablilizing an emulsion, a suitable method should be used for coalescence of small suspended droplets to form larger ones, to facilitate separation. The method of separation can not be generalized, as each emulsion is unique but some methods seem to be more promising than others.

Methods involving membranes with different wetting properties, plates of various materials, a combination of mechanical force and coalescers, electrostatic field and chemicals have been investigated.

Besides the coalescence of fine suspended particles, the difference in specific gravities between oil (or bitumen) and water is an important factor in their separation. This factor is more considerable when heavy oil and bitumen have a low degree of °API. To increase the difference of specific gravities between the water and oil phases, two techniques, heating and dilution are used where it is necessary.

When the specific gravity of the oil is reduced, destabilizing the emulsion will be speeded up, and coalescence of fine suspended droplets takes place sooner.

The presence of small amounts of water-in-oil stable emulsions and their separation is the main problem in dehydration of the produced oil. Besides the two commercialized methods of electrostatic field treatment and high temperature treatment, which are costly, an emerging method with a smaller cost of operation is the application of membranes of hollow-fibre with hydrophilic and hydrophobic medias.

19.0 IDENTIFICATION OF PROMISING METHODS (cont'd)

In this method water is forced to pass through the hydrophilic media and oil through the hydrophobic one. The design of the membrane is more effective when oil and water droplets are forced to pass over a large surface area, together with a mechanical coalescence. This may be a promising method, at least for some of the emulsions. To use such a system, pretreatment, might be necessary to destabilize fine solids and collect them in the water phase. At present, demulsifiers are the only materials which are effective in destablizing fine suspended solids in an emulsion.

19.1 Recommendations for Future Work

It is recommended that a major effort in the area of filtration be considered. This recommendation is reached, to some extent, by exclusion of the other techniques due to present and potential difficulties. Spherical agglomeration is and probably will remain a coal utilization scheme, not a bitumen recovery scheme. To transform it into a scheme to break bitumen in water emulsions , would require regeneration of the dry or water-wet coal, i.e. a process probably more difficult than breaking the original emulsion by any other means. Electrostatic means, if feasible, would almost certainly prove to be prohibitively expensive, thereby ruling out an otherwise attractive concept. An electrostatic treatment would not leave traces in either the product or the tailings. A chemical treatment by means of surfactants could be costly too, and might also produce very significant environmental problems. In addition, very significant problems may be encountered with the use of surfactant treatments, e.g. inversion of the emulsion under certain conditions.

19.0 IDENTIFICATION OF PROMISING METHODS (cont'd)

19.1 Recommendations For Future Work (cont'd)

This line of reasoning leads, with necessity, to filtration as a potential technique to break bitumen in water emulsions. Just like electrostatic processes, the treatment would leave no traces, and the cost of operation would be substantially less than that of an electrostatic plant. The key point is that with membrane filters it is possible to allow selectively the passage of water through a hydrophilic filter as well as oil through a hydrophobic filter. The possibilities of such "upstream" separations should be carefully explored. It has been shown that filters having both hydrophilic and hydrophobic domains break oil in water emulsions and produce a phase separation down-stream. These possibilities should be fully studied, from three aspects: 1. Two phase incompressible flow; 2. Surface properties of filter materials (surface tensions, contact angles, wettability); 3. Filter design (shapes, sizes, distribution of hydrophobic and hydrophilic sites).

Filtration membranes are now available with a variety of properties and at a cost which may well be acceptable. The two most attractive aspects of these membranes probably are the facts that the pore sizes and pore distribution can be tailored to almost any specifications and that the pressure drop across the filtration unit is relatively small, due to the very small thickness of the membranes. The latter fact has benefits for the design as well as the energy cost of operation. Nevertheless, such membranes are fragile, and it is recommended that a search be made for alternative filters. As a point of departure one might think of a filter of quartz-sand where certain domains of the sand would be rendered hydrophobic by a pretreatment with a suitable silicone compound.

19.1 Recommendations for Future Work (cont'd)

There is one fact which may require special attention. The presence of clay at the bitumen-water interface may stabilize the emulsion to such an extent that it cannot be broken by filtration. If this should occur, the clay would have to be removed from that interface prior to filtration. Given a choice of bringing the clay into the aqueous or the hydrocarbon phase, one will presumably opt for the aqueous phase. This necessitates making the clay particles more hydrophilic. In practical terms this means treatment of the emulsion with polymeric surfactants. While potentially undesirable from an environmental point of view, it must also be realized that the surfactant concentration needed to remove the clay from the oil/water interface is significantly lower than that required for breaking the solution. Unfortunately, such a treatment aimed at removing clay particles from the interface may generate problems in the disposal of the tailings, as the resulting clay suspension may be very stable. At least two lines of attack of this problem are conceivable:

1. Perhaps polymeric surfactants of intermediate hydrophilic nature could be used, so that aggregation or agglomeration of suspended clay particles might still be feasible.

2. Clay particles will normally be negatively charged. It may be possible to incorporate some negative charges into the polymeric surfactant without impeding the detachment of the clay particles from the oil/water interface. This would leave the clay particles even more negatively charged, which would increase the stability of the suspension, but, more importantly, would increase the electrophoretic mobility and hence facilitate removal by electrostatic fields in electrostatic precipitators.

19.0 IDENTIFICATION OF PROMISING METHODS (cont'd)

19.1 Recommendations for Future Work (cont'd)

Schemes of a separate filtration to remove clay from suspension, optimizing the adhesion characteristics of the clay to the filter, are also conceivable.

SECTION VI

CONCLUSIONS AND RECOMMENDATIONS

20.0 CONCLUSIONS

- The state-of-the-art methods available for oil/water separation are technically adequate to meet the needs of the industry. However, these are being utilized only by 6% of the oil producers.

- The cost of complete dehydration of the produced oil is high. This is particularly high for dehydration of oil using various evaporation techniques currently being employed in the industry. This can be drastically reduced by developing a system which will combine this technique with others.

- The use of 10 to 15% light hydrocarbon condensate or higher percentage of other oil fractions as diluent to increase the ^{o}API of the heavy oil and bitumen improves the oil/water separation performance. Commercial systems based on this principal are being developed by enterprising manufacturers.

- No commercial method has been developed to-date to treat the tailings containing colloidal clays economically.

- Tests have confirmed our findings that:
  - removal of organic and inorganic solid precipitates directly effects the separation efficiency and the feed rate, and
  - emulsions have different degrees of stability and more stable emulsions need a higher treating temperature for separation.

21.0 RECOMMENDATIONS

- In-depth technical study of all treating plants should be carried out to improve the efficiency, increase profitability and make this sector of the industry more competitive.

- The development of optimized treating systems, incorporating the state-of-the-art technology, should be carried out. This would meet the needs for various sectors of the industry in overcoming the prevailing technical problems and improving the efficiency of oil/water separation.

- A research program to develop energy efficient methods of oil/water separation based on the promising emerging methods should be implemented. In particular, the program should include the following:
  - Application of coalescing systems with hydrophilic and hydrophobic membranes.
  - Application of various filtering systems including hollow fibers as porous medias where a large surface area can be created, in contact with the emulsion.
  - Application of mechanical coalescers, using absorbent materials requiring low energy consumption and little maintenance.
  - Study of the nature of stabilizing agents of heavy oil and bitumen, including organic and inorganic compounds. The aim would be to determine suitable chemical compounds for destabilizing the heavy oil and bitumen mixtures.

REFERENCES

1. Berkman Egloff "Emulsion and Foam" Chapter 3, Practical Knowledge of Emulsions, Demulsification, Published by Reinald Publishing Company, pp. 219-386, 1941.

2. Joe Stires SPE, Conoco Inc. "Design of a High-Rate, High-Volume Oil/Water Separator", Journal of Petroleum Technology (AIME), November 1982.

3. J.A. Zeevalkink and J.J. Brusman, "Oil removal from water in parallel plate gravity - type separators", Water Res. Vol. 17, No. 4, P.P. 365-373, 1983.

4. L. Boyadzhiev, G. Kyutchoukov and co-workers, "Separator for removal of organic liquids dispersed in water". Filtration and separation, January/February, 1981.

5. G. Dhawan, "Treatment and Recovery of Emulsified Oil by Ultra Filtration", conference proceedings (EM & R 000788).

6. P.R. Klinkowski, "Ultrafiltration, An Emerging Unit Operation", Chemical Engineering, pp. 165-173, May 8, 1978.

7. James M. Bollinger, "New Filtration Concept Uses Electro Deposition", Chemical Engineering, pp. 38 and 39, May 14, 1984.

8. New Decanter Centrifuge Solves Sludge Problems in Treatment Plants, using Centrifuge. E & MJ, January 1982.

9. Kenneth J. Lissant, " Emulsification and Demulsification in Oil Recovery" in Improved oil Recovery by Surfactant and Polymer Flooding, editing by D.O. Shah and R.S. Schechuter, pp. 93, 1977.

10. S.J. Rehm and R.J. Shanghnessy, C.E. NATCO "Enhanced Oil Water Separation, the Performax , SPE 11562, Petroleum Engineers of AIME, 1983.

11. Leslie Burt, "New System Solves Filtration Problems", Canadian Chemical Processing, pp, 64-66, August - September 1984.

12. Linden Bland, "Murphy Oil outlines Emulsion Breaker", Synfuel Week,pp. 3 and 4, February 27, 1984.

REFERENCES (cont'd)

13. R.G. Gorrill/P. Kitzan/D.P. Komery, Shell Canada Resources Limited, " The Design of the Peace River in-situ Oil Sands Pilot Project", May 1979, corrected 1980.

14. Heavy Oil Report, Oil Week Journal, pp.26, March 14, 1983.

15. Kenneth J. Lissant, "Demulsification Industrial Applications" Surfactant Science Series, Vol. 13, pp. 105-134, 1983.

16. Klaus J. Zanker, " Radio Wave Interface Detector Measures Low Concentration of Oil in Water, Control Dumping", Oil and Gas Journal, pp.150 - 152, January 30, 1984.

17. Separation and Recovery System, Processing, pp. 19, February 1982.

18. Separation Systems Reduces Effluent, Processing, pp. 35. May 1983.

19. D.R. McCoy, R.M. Gipson, K.B. Young, Texaco Inc., Texaco Canada Inc., "Demulsification of Bitumen Emulsions with a High Molecular Weight Mixed Alkylene Oxide Polylol", U.S. patent No. 4231, 146, March 1982.

20. D.R. McCoy, C.L. Laberge, Texaco Inc., Texaco Canada Inc., "Demulsification of Bitumen Emulsions with a High Molecular Weight Polyal Containing Discrete Blocks of Ethylene and Propylene Oxide", U.S. patent No. 4321, 147, March 23, 1982.

21. D.R. McCoy, R.M. Gipson, K.B. Young, C.L. Laberge, Texaco Inc., Texaco Canada Inc., "Demulsification of Bitumen Emulsions", U.S. patent No. 4321-148, March 1982.

22. M.S. Patel, A. Sacuta, Texaco Exploration Canada Ltd., "Demulsification of Oil Emulsions with a Mixture of Polymers and Alkaline Earth Metal Halide", U.S. patent No. 4058, 453, November 15, 1977.

23. R.F. Bialek, Texaco Canada Inc., "Tar Sands Emulsion-Breaking Process", U.S. patent No. 4302, 326, November 24, 1981.

24. B.W. Allen, Texaco Canada Inc., "Demulsifying petroleum Emulsions with Aryl Sulfonates - Oxyalkylated Phenoloformaldelyde Resins and Alkali Metal Halides", U.S. patent No. 4299, 690, November 1981.

REFERENCES (cont'd)

25. R.F. Bialek, Texaco Canada Inc., "Process for Breaking Emulsions in Fluids from in-situ Tar Sands Production", U.S. patent No. 4272, 360, June 9, 1981.

26. J.R. Farnand, "The Treatment of Heavy Oil Emulsions with Short Chain Polar Additives", a National Research Council Canada's Report, Chemistry Division, Report No. CI 090-81S, December 16, 1981.

27. K.E. Pope, Combustion Engineering Inc., Windsor, Conn., "Electrostatic Coalescing System", U.S. patent No. 4 200 516, April 29, 1980.

28. W.H. McNeese and P.C. Wankat, "Emulsion Separation by Single Wire HGMS", IEEE transactions on magnetics, Vol. MAG-16, No. 5, September 1980.

29. H.R. Bull "Energy Saving Heavy Crude Oil Emulsion Treating Method and Apparatus for Use Therewith", U.S. patent 4329, 159, May 11, 1982.

30. Donald R. Burris, "Energy Dollars (AC/DC) Electrostatic Oil Dehydration and Desalting", C.E. NATCO, publications.

31. Bitter, Johan George Albert, Shell International Research, "Process and Plant for Breaking of Water Oil Emulsions", European patent application No. 90200261.8, October 1980.

32. C.B. Tanny and D. Hank, "Filtration of Particulates and Emulsions with a Pleated, Thin Channel, Cross-Flow Module", Separation Science and Technology 15(3), pp. 317-337, 1980.

33. C.E. Capes, R.D. Colement and W.L. Thayer, "Treatment of Crude Petroleum/Water Emulsions by Agglomeration Methods Using Fine Coal", NRC, 1982.

34. C.E. St. Denis and M.A. Kessick, "Recovery of Residual Bitumen from Oil Sand Sludges", The Canadian Journal of Chemical Engineering, Vol. 60, pp. 675, October 1982.

35. "A New Technique for Clay Settling", electro-endosmosis, developed by Monsanto Enviro-Chem., issued at chemical week, January 25, 1984.

REFERENCES (cont'd)

36. Marvin J. Weintraub and his co-workers, "Method for Breaking an Oil-in-Water Emulsion", using porous ferrous ion as anode for an oil/water emulsion passing through, using an electric current, U.S. patent 4, 194, 972, March 25, 1980.

37. SNC report, Investigation to Develop or Innovate Methods for the Removal of Oxygen from Coals (Phase II).

38. J.C. Kloepter, "Process Design for the Re-use of Waste Water for Oil Production". Presented at Alberta Oil Sands Technology and Research Authority's 4th annual "Advances in Petroleum Technology" conference, May 30-31, 1983.

39. B.H. Asano and J. Kus, "Overview of the Status of the Treatment and Recycle of Produced Water in In-Situ Recovery". May 30-31, 1983.

40. Robert Burton, "Waste Water Recycling in Steamflood Operations", SPE 11710, March 23-25, 1983.

41. Don Bartley, How Baker Engineering Inc., Tyles Texas, "Heavy Crude, Stocks Pose Desalting Problems", presented at World Oil and Gas Conference, Dallas, December 14-17, 1981. Reprinted from February 1, 1982 of Oil and Gas Journal.

42. Michael A. Carrel, "Reclaiming Produced Water for Steam Generation in the Kren River Field", SPE 8411, September 25-26, 1979.

43. Cold Lake Project, "A Report to the Energy Resources Conservation Board by Imperial Oil Limited", pp. 6, 22-24, May 1978.

44. R.E. Bretz and Co-workers, " A Small-Volume Continuous Oil/Water Separator for Laboratory Displacement", Journal of Petroleum Technology, pp. 487, March 1984.

45. Thomas L.Bose, "New Mechanical Caolescing Medium is Used in Treaters", Oil and Gas Journal, pp. 82 and 83, January 23, 1984.

46. Sheldon D. Strauss, "Technology Advances Improve Outlook for Membrane Treatment", Power Journal, pp. 19, February 1983.

REFERENCES (cont'd)

47. "Ultra Filtration Systems Handle Wide Range of Jobs", Chemical Engineering Journal, pp.32, October 31, 1983.

48. Foppe B. Dewalle and Co-workers, "Organic Carbon Removal by Advanced Waste Water Treatment Processes", Environmental Scientific Technology, Vol. 16, No. 11, pp. 741-743, 1982.

49. L.A. Spielman and Y.P. Su, Harvard University , "Coalescence of Oil-in-Water Suspensions by Flow Through Porous Media", Industrial & Engineering Chemistry Fundamentals, Vol. 16, No. 2, pp. 272-282, 1977.

50. D.G. Cooper and Co-Workers, University of Western Ontario , "The Role of "HLB" To Demulsification of a Mixture of Heavy Oil, Water and Clay", The Canadian Journal of Chemical Engineers, Vol. 58, pp. 576-579, October 1980.

51. J.E. Son and Co-workers, University of Ottawa, "Effect of Petroleum Sulfonates, Liquid-Sulfonate Surfactant Mixtures on the Coalescence Behaviour of Oil Droplets", The Journal of Canadian Petroleum Technology, pp. 42-48, July - August 1982.

52. J.F. Boyee and Co-Workers, "The Measurement of Surface and Interfacial Tension by the Axi-Symetrical Drop Technique", Colloids and Surfaces, Vol. 9, pp. 307, 317, 1984.

APPENDIX A

TABLE A-1 - SOURCE LIST OF INFORMATION AND CONTACTS

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4th Floor, Terrace Plaza
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Energy Resources Conservation Board (ERCB)
640 Fifth Ave., S.W.
Calgary, Alberta
T2P 3G4

Tel: (403) 297-8311

The University of Oklahoma at Norman
Office of the Director, Energy Resources Centre
601 Elm, Room 145
Norman, Oklahoma

Dr Donald Menzie
Tel: (405) 360-1600

Sask Oil Regina
515 Henderson Drive
Regina, Saskatchewan
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Tel: (306) 924-0757

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APPENDIX A
TABLE A-1 - SOURCE OF INFORMATION AND CONTACTS (Cont'd)

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National Institute for Petroleum and Energy Research (NIPER)
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Bartlesville, Oklahoma
74005

Ken Spence
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American Petroleum Institute (API)
1220 L Street, N.W.
Washington, D.C. 2005

Walter C. Retzseh
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Colt Engineering Corporation
526 - 10333 Southport Rd. S.W.
Calgary, Alberta
T2W 3X6

Wayne J. Egan
Tel: (403) 253-9305

Corpus Information Service
1450 Don Mills Road
Don Mills, Ontario
M3B 2X7

Bob Douglas
Tel: (416) 445-7101

APPENDIX A

TABLE A-2 - LIST OF THE EQUIPMENT SUPPLIERS

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Supplier	Equipment
C.E. NATCO Limited A Subsidiary of Combustion Engineering Inc. P.O. Box 850, Station T. Calgary, Alberta T2H 2H3 Tel: (403) 236-1850	- Oil and gas separators - Free water knockout (FWKO) - Heater treater - Thermoelectrostatic treater - Performax (FWKO, Coalescer)
ABAX Energy Services Ltd. 5929 - 6th Street, N.E. Calgary, Alberta T6K 5R5 Tel: (403) 275-6260	- Separators - Heaters (for direct and indirect heating) - Dehydrator
HTI Technology Canada Ltd. #10, 2235 - 30th Avenue N.E. Calgary, Alberta T2E 7C7 Tel: (403) 230-1606 (supplying the fabricated equipment designed by HTI)	- Free water knockout (FWKO) - Heater treater - Thermoelectrostatic treater - Desalter
Universal Industries Ltd. Box 1590 Lloydminster, Alberta S9V 1K5 Tel: (403) 875-6161	- Heater treaters - Thermoelectrostatic treater
SIVALLS Inc. P.O. Box 2792 Odessa, Texas 79760 Odessa, Texas 79760 U.S.A. Tel: (915(337-3571	- Separators (low and high pressure) - Water knockout - Heater treaters - Heaters - Water treatment equipment

APPENDIX A
TABLE A-2 - LIST OF THE EQUIPMENT SUPPLIERS (Cont'd)

Supplier	Equipment
Latoka Engineering 4900 So. Lewis Tulsa, Oklahoma 74105 U.S.A. Tel: (918) 747-2771	- Free water knockout (low pressure) - Heater treater - Stream dividers
Howe Baker Engineers, Inc. P.O. Box 956 Tyler, Texas 75701 U.S.A.	- Electrostatic treater - Crude dehydration, desalter - Separators - Treaters
Wemco 5155 Creekbank Road Missisauga, Ontario L4W 1X2 Tel: (416) 625-1637	- Depurator (Hydrocleaner floataton) - Gravity Separators - Vibrating centrifuge
KHD Canada Inc. Humboldt Wedag Division 90 Montee de Liesse Montreal, Quebec H4T 1N4 Tel: (514) 341-1830	- Centrifuge for solid liquid separation
Alfa-Laval Limited 205 - 5th Avenue S.W. Bow Valley Squarell Suite 3040 Calgary, Alberta T2P 2V7 Tel: (403) 265-1988	- Centrifuge (disk-stack) (for 3 phase separation)
Degrémont Infilco Ltée 3300, Cote Vertu Montreal, Quebec H4R 2B7 Tel: (514) 337-2010	- Dissolved air floatation

APPENDIX A
TABLE A-2 - LIST OF THE EQUIPMENT SUPPLIERS (Cont'd)

Supplier	Equipment
The Dorrion Company, Inc. 9542 Hardpan Road Angola, New York 14006 Tel: (716) 549-2500	- Pressure lead filters - Tubular filters - Polypropylene filter press plates - Water treatment facilities - Multitube coolers
Fram Canada Inc. P.O. Box 550 305 Romeo St. S. Strafford, Ontario N5A 6V4 Tel: (519) 271-3470	- C.P. coalescing plate separator (for separation of oil/water and solid)
Ecodyne Ltd. 2201 Speers Road Oakville, Ontario L6L 2X9 Tel: (416) 827-9821	- Sand filter - Spray deaerator - Separators - Coalescer - Gravity filters - Water treatment facilities
Reynord 1181 Sheppard Ave. E. Willowdale, Ontario M2K 1C6 Tel: (416) 221-9361	- Dissolved air flotation
Preeisioneering 303 Nantucket Blvd. Scarborough, Ontario MIP 2P2 Tel: (416) 751-9200	- Corrogated plate separator

APPENDIX A
TABLE A-2 - LIST OF THE EQUIPMENT SUPPLIERS (Cont'd)

Supplier	Equipment
Dorr-Oliver Canada 174 West Street South Orillia, Ontario L3V 6L4 Tel: (705) 325-6181 (416) 363-8781	- Waste water treatment clarifier - Thickening facilities
B. & D. Engineering Sales No. 2, 6025 - 12th St. S.E. Calgary, Alberta T2H 2K1	- Metering pump - Mixer - Tank package

APPENDIX A

TABLE A-3 - LIST OF THE OIL COMPANIES AND CONTACTS

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Home Oil Company Ltd.
2300 Home Oil Tower
324, 8th Avenue S.W.
Calgary, Alberta
T2P 2Z5

C.N. Lagel
Tel: (403) 232-7100

Alberta Energy Company Ltd.
2400, 639 5th Avenue S.W.
Calgary, Alberta
T2P 0M9

B.B. Wells, P. Eng.
Tel: (403) 266-8111

Norcen Energy Resources Ltd.
Norcen Tower
715 - 5th Avenue S.W.
Calgary, Alberta
T2P 2X7

T.G. Beale
Tel: (403) 231-0111

Drummond Oil & Gas Ltd.
2100 - 5th Avenue Place, 425
1st Street, S.W.
Calgary, Alberta
T2P 3LB

D.C. Kesteven
Tel: (403) 269-8850

Texaco Canada Resources Ltd.
Energy Resources & Technology Division
605 - 5ath Avenue S.W.
P.O. Box 3333, Station "A"
Calgary, Alberta
T2P 2P8

I.E. Varga
Tel: (403) 267-0000

APPENDIX A

TABLE A-3 - LIST OF THE OIL COMPANIES AND CONTACTS (Cont'd)

Murphy Oil Company Ltd.
P.O. Box 2721
1700, 800 - 6th Avenue S.W.
Calgary, Alberta

Linden Byland
Tel: (403) 294-8000

Shell Canada Resources Ltd.
P.O. Box 100, STN "M"
Calgary, Alberta
T2P 2H5

R.G. Corrill
Tel: (403) 232-3111

Dome Petroleum Ltd.
Box 1379, Lloydminster,
Alberta
S9V 1K4

L.G. Rodwell
Tel: (403) 871-6107

Saskatchewan Oil and Gas Corporation (SASKOIL)
1000 Grenfell Tower, 1945 Hamilton Street
P.O. Box 1550
Regina, Sskatchewan
S4P 3C4

Dick Parker
Tel: (306) 566-9700

Pan Canadian Petroleum Ltd.
P.O. Box 2850
Calgary, Alberta
T2P 2S5

J.W. Uibel
Tel: (403) 290-2000

APPENDIX A
TABLE A-3 - LIST OF THE OIL COMPANIES AND CONTACTS (Cont'd)

Petro Canada Inc.
P.O. Box 2844
Calgary, Alberta
T2P 3E3

D.E. Towson
Tel: (403) 296-8000

Mobil Oil Canada Ltd.
P.O. Box 800
Calgary, Alberta
T2P 2J7

Tel: (403) 268-7910

Amoco Canada
Petroleum Company Ltd.
Amoco Canada Building
444 - 7th Avenue S.W.
Calgary, Alberta
T2P 0Y2

Jeof Spalding
Tel: (403) 233-1313

Union Oil Company of Canada Ltd.
335 - 8th Avenue S.W.
Post Office Box 999
Calgary, Alberta
T2P 2K6

A.D. Hugh
Tel: (403) 268-0176

Gulf Oil Exploration & Production Company
P.O. Box 471
Columbia, M.S. 39429
U.S.A.

J.P. Campbell
Tel: (601) 736-5356

APPENDIX A
TABLE A-3 - LIST OF THE OIL COMPANIES AND CONTACTS (Cont'd)

Marathon Oil Company
P.O. Box 277
Bridgeport, Illinois 62417

J.C. Howell
Tel: (618) 945-2011

Gulf Canada Resouorces Inc.
P.O. Box 130
Calgary, Alberta
T2P 2H7

D.J. Lovitt
Tel: (403) 233-4000

Husky Oil Operation Ltd.
P.O. Box 6525
Postal Station "D"
Calgary, Alberta
T2P 3G7

S. Huk
Tel: (403) 298-6111

Esso Resources Canada Ltd.
Heavy Oil Dept.
Esso Plaza 237 - 4th Avenue S.W.
Calgary, Alberta
T2P 0H6

G.C. Marriland
Tel: (403) 237-3737

APPENDIX A

TABLE A-4 - LIST OF CHEMICAL SUPPLIERS AND CONTACTS

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Baker Oil Treating
Division of Magnachem Limited
A Baker Oil Tools Company
6224 - 29th Street S.E.
Calgary, Alberta
T2C 1W3

Lou Scarpino
Tel: (403) 279-8959

ALCHEM Inc.
P.O. Box 6120, Station "C"
Edmonton, Alberta
T5B 4K5

G.E.T. Simpson, ph.D.
Tel: (403) 468-5255

Petrolite Corporation of Canada, Limited
Tetrolite Division
1145J - 44th Avenue S.E.
Calgary, Alberta
T2G 4X4

Tim W. Kennedy
Tel: (403) 243-5424

Sybron/Gamlen
Gamlen Chemical Division
Sybron Canada Limited
595 Guimond Blvd.
Longueuil, Quebec
J4G 1L9

P. Fonsato
Tel: (514) 679-6060

Henkel Chemical Canada Ltd.
7075 Fir Free Drive
Mississauga,
Toronto, Ontario
L5S 1J7

Brian Jones
Tel: (514) 353-7550

APPENDIX A

TABLE A-4 - LIST OF CHEMICAL SUPPLIERS AND CONTACTS (Cont'd)

Champion North Western Chemical, Ltd.
6555 - 30th St. S.W.
Calgary, Alberta
T2C 1R4

Jim Carlile
Tel: (403) 279-2835

Nutro Oil Field Chemicals
P.O. Box 21187
Houston, Texas 77226

L.A. Rein
Tel: (713) 675-3421

Di-Chem, Dresser Canada Inc.
1304, 505-3rd Street S.W.
Calgary, Alberta
T2P 3E6

Wayne Mueller
Tel: (403) 290-5300

WITCO Chemical Canada Ltd.
2 Lansing Square, suite 1200
Willowdale, Ontario
M2J 4Z4
Donna, Buckingham

Tel: (416) 497-9991